

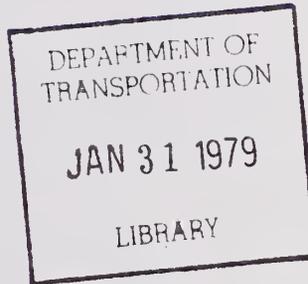
TE  
662  
A3  
NO.  
FHWA-  
RD-  
78-24  
C.2

Report No. FHWA-RD-78-24

# INTEGRATED MOTORIST INFORMATION SYSTEM (IMIS) FEASIBILITY AND DESIGN STUDY

## Phase II: Generalized Methodology for IMIS Feasibility Studies

### Vol. 2 Validation and Application of Feasibility Study Handbook



**May 1978**  
**Final Report**

Document is available to the public through  
the National Technical Information Service,  
Springfield, Virginia 22161

Prepared for  
**FEDERAL HIGHWAY ADMINISTRATION**  
**Offices of Research & Development**  
**Washington, D. C. 20590**

## FOREWORD

This report presents the results of the application and validation, in a specific corridor, of a methodology for performing a feasibility study for an Integrated Motorist Information System (IMIS). The report is intended for use as an adjunct to Volume 1, "IMIS Feasibility Study Handbook," FHWA-RD-78-23. This handbook is a guide for performing a feasibility study for an IMIS in a given corridor; it also contains information on costs and tradeoff considerations for the selection of traffic surveillance and control subsystem elements and techniques. The handbook documents the methodology used in the study reported herein.

These two volumes constitute the Final Report on Phase II: Generalized Methodology for IMIS Feasibility Studies, which is the second of three phases of the "Integrated Motorist Information System Feasibility and Design Study," conducted for the Federal Highway Administration, Office of Research, Washington, D.C., by Sperry Systems Management under Contract DOT-FH-11-8871.

Phase I, a feasibility study for an IMIS in the Northern Long Island Corridor in New York State, was reported in three volumes: Final Report, FHWA-RD-77-47; Appendices, FHWA-RD-77-48; and Executive Summary, FHWA-RD-77-49. Phase III will result in the final design for an IMIS in the corridor studied in Phase I.

Sufficient copies of this report are being distributed by FHWA Bulletin to provide a minimum of one copy to each FHWA Regional Office, one copy to each FHWA Division Office, and one copy to each State highway agency. Direct distribution is being made to the Division offices.

A limited number of additional copies for official use are available upon request from the Systems Development and Technology Group, HRS-32, Traffic Systems Division, Office of Research, FHWA, Washington, D.C. 20590.



Charles F. Scheffey  
Director, Office of Research

## NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

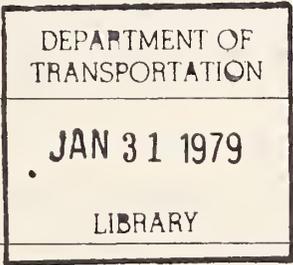
The contents of this report reflect the views of Sperry Systems Management, which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policy of the Department of Transportation.

This report does not constitute a standard, specification, or regulation.

TE  
662  
A3  
no.  
FHWA-  
RD-  
78-24  
C.V.

Technical Report Documentation Page

1. Report No. <b>FHWA-RD-78-24</b>		2. Government Accession No.		3. Recipient's Catalog No.									
4. Title and Subtitle <b>INTEGRATED MOTORIST INFORMATION SYSTEM (IMIS) FEASIBILITY AND DESIGN STUDY Phase II: Generalized Methodology for IMIS Feasibility Studies Volume 2 - Validation and Application of Feasibility Study Handbook</b>		5. Report Date <b>May 1978</b>		6. Performing Organization Code									
		7. Author(s) <b>P. Zove, C. Berger</b>		8. Performing Organization Report No. <b>GF-15-1006 (NP)</b>									
		9. Performing Organization Name and Address <b>Sperry Systems Management Sperry Rand Corporation Great Neck, New York 11020</b>		10. Work Unit No. (TRAIS) <b>FCP-32C3-012</b>									
12. Sponsoring Agency Name and Address <b>Offices of Research and Development Federal Highway Administration U.S. Department of Transportation Washington, D. C. 20590</b>		11. Contract or Grant No. <b>DOT-FH-11-8871</b>		13. Type of Report and Period Covered <b>Final Report January 1977 - May 1978</b>									
		14. Sponsoring Agency Code		15. Supplementary Notes <b>FHWA Contract Manager: L. D. Powers (HRS-32)</b>									
16. Abstract <p>Phase I of the IMIS project examined the feasibility of implementing an Integrated Motorist Information System in a corridor located in New York (northern Long Island). The results are documented in report numbers FHWA-RD-77-47, 48, and 49 Under Phase II of IMIS (the present phase) the methodology for performing an IMIS feasibility study was generalized and put into "Handbook" form for use by practicing traffic engineers. The Handbook is printed as a separate document, as identified below.</p> <p>This report reviews the Phase II activities and presents the results of applying the Handbook to a "test corridor" in California and the validation of the benefit assessment methodology. The application provides a complete example of an IMIS feasibility study and should therefore be of particular interest to Handbook users.</p> <p>This volume is the second in a series. The other volume in the series is:</p> <table border="1"> <thead> <tr> <th><u>Vol No.</u></th> <th><u>FHWA No.</u></th> <th><u>Short Title</u></th> <th><u>NTIS (PB) No.</u></th> </tr> </thead> <tbody> <tr> <td>1</td> <td>78-23</td> <td>IMIS Feasibility Study Handbook</td> <td>(not yet available)</td> </tr> </tbody> </table>						<u>Vol No.</u>	<u>FHWA No.</u>	<u>Short Title</u>	<u>NTIS (PB) No.</u>	1	78-23	IMIS Feasibility Study Handbook	(not yet available)
<u>Vol No.</u>	<u>FHWA No.</u>	<u>Short Title</u>	<u>NTIS (PB) No.</u>										
1	78-23	IMIS Feasibility Study Handbook	(not yet available)										
17. Key Words <b>Motorist Information Systems, Traffic Surveillance and Control Systems, Freeway Corridor Control Systems, Route Diversion, Benefit/Cost Analysis</b>			18. Distribution Statement <b>No restrictions. This document is available to the public through the National Technical Information Service Springfield, Virginia 22161</b>										
19. Security Classif. (of this report) <b>Unclassified</b>		20. Security Classif. (of this page) <b>Unclassified</b>		21. No. of Pages <b>167</b>	22. Price								



## ACKNOWLEDGMENT

The Sperry Systems Management staff wishes to acknowledge the assistance and guidance provided during the course of the study by Mr. Lawrence D. Powers, the IMIS Contract Manager for the Federal Highway Administration.

Special thanks are also due to members of the Freeway Operations Branch of the California Department of Transportation for their excellent cooperation during the data collection portion of the study.

## TABLE OF CONTENTS

Section		Page
1	INTRODUCTION AND SUMMARY	1
	1.1 Introduction	1
	1.2 Phase II Overview	1
	1.3 Handbook Testing and Validation Approach	3
	1.4 Summary of the Handbook Testing and Validation	5
	1.5 Report Organization	11
2	SELECTION OF TEST CORRIDOR	12
3	IMIS APPLICABILITY STUDY	16
	3.1 Introduction	16
	3.2 Application of the Qualitative Guidelines	16
	3.3 The "Maximum Possible" Benefit/Cost Calculation	17
	3.4 The "Expected" Benefit/Cost Ratio	19
4	PLANNING AND SCHEDULING THE FEASIBILITY STUDY	22
5	INITIAL SCREENING OF ROUTES	24
6	ASSEMBLY OF CORRIDOR DATA BASE	29
7	SUPPLEMENTAL ANALYSES	35
	7.1 Introduction	35
	7.2 Control Probability Model Coefficients	35
	7.3 Accident/Incident Rates	35
	7.4 Alternate Route Capacity Analysis	42
	7.5 Origin-Destination Pattern	42
	7.6 Median Trip Length	46
8	ALTERNATE ROUTE ANALYSIS	48
	8.1 Introduction	48
	8.2 The Primary and Alternate Routes	48
	8.3 Ranking of Alternate Routes	50
	8.3.1 Alternates for Primary Route I-10	50
	8.3.2 Alternates for Primary Route Cal 60	53
	8.3.3 Alternates for Primary Route I-210	53
	8.4 Summary	53

## TABLE OF CONTENTS (Continued)

Section		Page
9	ROADWAY NETWORK CONFIGURATIONS	55
	9.1 Introduction	55
	9.2 Network Configurations	55
	9.3 Discussion	60
10	ESTABLISHMENT OF CONTROL AREA BOUNDARIES	62
	10.1 Introduction	62
	10.2 Control Subnetworks	62
	10.3 Subnetwork Control Probability Factors	63
	10.4 Control Volume Shift Level	66
11	REVIEW OF SYSTEM FUNCTION AND CONTROL POLICY	67
12	EQUIPMENT SELECTION FOR IMIS SUBSYSTEMS	68
	12.1 Introduction	68
	12.2 Equipment and Unit Costs	68
	12.2.1 Variable Message Signs (VMS)	68
	12.2.2 Fixed Message Signs	77
	12.2.3 Highway Advisory Radio	77
	12.2.4 Entrance Ramp Control	78
	12.2.5 Freeway Surveillance	78
	12.2.6 Arterial Surveillance and Control	79
	12.2.7 Other System Surveillance	81
	12.2.8 Motorist Aid Callbox System	82
	12.2.9 Pre-trip/Enroute Information Services	83
	12.2.10 Equipment Cabinets	84
13	DEVELOPMENT OF ALTERNATIVE PRELIMINARY SYSTEM DESIGNS	85
	13.1 Introduction	85
	13.2 Candidate A1	85
	13.3 Candidate A2	94
	13.4 Candidates B1 and B2	98
	13.5 Candidates C1, C2, D1, and D2	101
14	DETERMINATION OF SYSTEM COSTS	105
	14.1 Introduction	105
	14.2 Costs for Candidate A1	105

TABLE OF CONTENTS (Continued)

Section		Page
	14.2.1 Variable Message Signs	105
	14.2.2 Fixed Signing	106
	14.2.3 Highway Advisory Radio	106
	14.2.4 Entrance Ramp Control	106
	14.2.5 Freeway Surveillance	107
	14.2.6 Arterial Surveillance and Control	107
	14.2.7 Communications	107
	14.2.8 Equipment Cabinets	111
	14.2.9 Control Center	111
	14.2.10 Pre-trip/Enroute Information Services	111
	14.2.11 Summary for Candidate A1	111
14.3	Costs for Other Candidate Systems	113
14.4	Cost Summary	113
15	DETERMINATION OF SYSTEM BENEFITS	122
	15.1 Introduction	122
	15.2 Benefit Development - Candidate A1	122
	15.2.1 Normal Congestion Benefits for Candidate A1	123
	15.2.2 Peak Period Incident Congestion Benefits for Candidate A1	124
	15.2.3 Off-Peak Incident Benefit - Candidate A1	128
	15.2.4 Accident Reduction Benefit - Candidate A1	128
	15.2.5 Fuel and Pollutant Benefits - Candidate A1	129
	15.3 Benefit Development - Candidate A2	129
	15.4 Benefit Development - Remaining Candidates	130
16	BENEFIT/COST EVALUATION OF ALTERNATIVE SYSTEMS	133
	16.1 Introduction	133
	16.2 Benefit/Cost Evaluation	133
	16.3 Discussion of Benefit/Cost Evaluation	136
	16.4 Benefit/Cost Sensitivity Analysis	139
	16.4.1 Benefit Sensitivity Analysis	139
	16.4.2 Cost Sensitivity Analysis	142
	16.4.3 Benefit/Cost Ratio Variation	144
	16.4.4 Discussion	144
17	CONCLUSIONS	147

TABLE OF CONTENTS (Continued)

Appendix		Page
A	VALIDATION OF FUNDAMENTAL BENEFIT RELATIONSHIPS	149
A.1	Introduction	149
A.2	Simulation Network and Scenarios	149
A.3	Comparison of Simulation and Methodology Benefit Data	153
A.4	Discussion	156

## LIST OF ILLUSTRATIONS

Figure		Page
1	IMIS Feasibility Handbook Task Sequence	4
2	The Test Corridor	15
3	Baseline Corridor Map	28
4	Data and Methodology Flow Chart	30
5	Balanced Freeway Volumes	33
6	Typical Hourly Volume Distribution	34
7	Accident Rate vs. Per Lane ADT	40
8	Origin-Destination Computation (I-10 Facility)	45
9	Baseline Corridor Map	49
10	Network Configuration A	56
11	Network Configuration B	57
12	Network Configuration C	58
13	Network Configuration D	59
14	Test Corridor with Subnetwork Boundaries	64
15	Typical Signing Configuration	70
16	Candidate Variable Message Sign and Highway Advisory Radio Locations	71
17	Variable Message Sign and Highway Advisory Radio Locations for Candidates A1 and A2	86
18	Variable Message Sign and Highway Advisory Radio Locations for Candidates B1 and B2	99
19	Variable Message Sign and Highway Advisory Radio Locations for Candidates C1 and C2	102
20	Variable Message Sign and Highway Advisory Radio Locations for Candidates D1 and D2	103
21	Incident Delay Diagram	126
22	Benefits vs. Costs for Candidate Systems	135
23	Simulation Network for Benefit Validation	150

## LIST OF TABLES

Table		Page
1	System Design Summary	9
2	Evaluation Summary for Alternative System Designs	10
3	Candidate Corridors for Methodology Validation	13
4	Annual Delay Caused by Congestion	19
5	Delay Saved with Control	21
6	Preliminary List of Corridor Roadways	25
7	Preliminary Assessment Chart	26
8	Data Types and Sources for the Test Corridor	31
9	Traffic Volume Data	36
10	Accident Statistics for I-10	38
11	Accident Statistics for Cal 60	39
12	Accident Rates (Converted Units)	41
13	Alternate Route Capacity Analysis	43
14	Ramp Listing for O-D Model (I-10 Facility)	44
15	Median Trip Lengths (MTL) on I-10	47
16	Alternate Route Scoring (Primary Route: I-10, Alternate Route: Valley Blvd)	51
17	Summary of Alternate Route Ranking	54
18	Typical Control Probability Factors	65
19	Worksheet for Estimating Number of Different Signing Configurations	72
20	VMS Sign Configurations	73
21	Arterial Surveillance and Control Unit Costs	80
22	Pre-Trip/Enroute Information Cost Data	84
23	Freeway Surveillance Requirements (Candidate System A1)	88
24	Arterial Surveillance Requirements (Candidate System A1)	90
25	Number of Field Cabinets and Communication Units, Freeways (Candidate System A1)	91
26	Number of Field Cabinets and Communication Units, Arterials (Candidate System A1)	92
27	Cable Pairs Required for Freeways	95

LIST OF TABLES (Continued)

Table		Page
28	Cable Pairs Required for Arterials	96
29	Cable Requirements Summary	97
30	System Design Summary	104
31	Freeway Surveillance Costs	108
32	Cable Cost Estimate Worksheet	109
33	System Cost Summary, Candidate A1	112
34	System Cost Summary, Candidate A2	114
35	System Cost Summary, Candidate B1	115
36	System Cost Summary, Candidate B2	116
37	System Cost Summary, Candidate C1	117
38	System Cost Summary, Candidate C2	118
39	System Cost Summary, Candidate D1	119
40	System Cost Summary, Candidate D2	120
41	Candidate System Cost Summary	121
42	Freeway Incident Rates	127
43	Candidate Design Effectiveness Rating	131
44	Benefit Summary for the Candidate Systems	132
45	Benefit/Cost Evaluation	134
46	Incremental Benefit/Cost Evaluation	137
47	Benefit/Cost Sensitivity Factors	140
48	Sensitivity Coefficients	141
49	Values Used in Benefit Sensitivity Analysis	141
50	Computation of Sensitivity Coefficients for System A2	142
51	Changes in Benefit as a Result of Component Variation	143
52	Cost Element Variations for System A2	145
53	Listing of Simulation Runs	152
54	Validation Experiments	153
55	Comparison of Normal Congestion Benefit Data	155
56	Comparison of Incident Congestion Benefit Data	157



## SECTION 1

### INTRODUCTION AND SUMMARY

#### 1.1 INTRODUCTION

An integrated Motorist Information System (IMIS) represents a combination of state-of-the-art technologies in real-time traffic surveillance, control and motorist information techniques to produce a fully coordinated corridor traffic management system.

The objective of IMIS is to obtain maximum utilization of existing roadways, in light of current congestion problems and social and economic pressures against major new roadway construction. The "integrated" approach allows remedial measures to be applied in combination, thus providing more effective solutions. Furthermore, the ability to "share" certain equipment elements (e. g. communications facilities) increases the system's cost-effectiveness.

A major objective of the FHWA-sponsored IMIS program is to implement an operational demonstration of the system, to verify the benefits of the approach and thus foster other implementations throughout the country. Following an evaluation of prospective locations for the demonstration, the Northern Long Island Corridor in New York was selected as the test site.

Phase I of the program, conducted in cooperation with the New York State Department of Transportation, consisted of a feasibility study to determine (1) whether the Long Island site provided all of the necessary characteristics to allow the IMIS concepts to be fully explored, and (2) whether sufficient improvements could be obtained to justify the system on a benefit/cost basis. The results of the study were positive, and plans are currently underway for proceeding with the system final design and PS&E (Phase III).

The present report deals with Phase II of the IMIS program which had as its objective the development of a user-oriented generalized methodology for performing an IMIS feasibility study in any corridor. An overview of the Phase II activities is presented in the paragraphs below.

#### 1.2 PHASE II OVERVIEW

To accomplish the Phase II objective, the study included the following four tasks:

- Definition of criteria and related data requirements to determine the applicability of IMIS to any given corridor;
- Specification of data requirements and data collection and analysis methods associated with the feasibility study;

- Development of the framework and methodology for performing the feasibility study;
- Testing and validation of the methodology.

The first task was geared toward providing the user with a technique for rapidly assessing whether his corridor would be a suitable site for IMIS. If so, the feasibility study would be conducted; if not the study could be terminated. This step recognized the fact that a credible IMIS feasibility study is not a trivial task. Thus, if negative results can be anticipated, a needless expenditure can be avoided.

The applicability procedure, as developed, consists of a three step process. The first step provides a series of qualitative guidelines and criteria for determining whether the roadway network possesses the overall geometric characteristics generally associated with an "IMIS corridor". These include factors such as the existence of a minimum of two major roadway facilities (at least one of which is a limited access facility) running the length of the corridor, corridor dimension aspects, availability of good connecting roadways, and well defined termini. Also included is a guideline for the existence of a minimum level of recurrent congestion. If the above guidelines are met the second step would be performed. This consists of a quantitative assessment of the potential benefit/cost ratio which could be achieved if IMIS could eliminate all of the present delay. The basic data requirements for this step are approximate values of speed in the congested sections during peak hours. Equations for calculating benefits were developed, along with approximate cost guidelines, so that a benefit/cost ratio could be estimated. If a benefit/cost ratio significantly greater than 1.0 is not achieved in this step, it signifies that the problems in the corridor are not sufficiently great to warrant an IMIS treatment, and the study is terminated. The third step (if performed) addresses the practical realization that only some fraction of the maximum possible benefits can be achieved by the system. This step entails some additional effort on the user's part, related primarily to an assessment of diversion potential in conjunction with present traffic conditions. Guidelines are provided, however, to simplify the assessment. Again, the results are used to compute a benefit/cost ratio, which should exceed 1.0 if the feasibility study is to be performed. This final step in the applicability procedure is, of course, not a substitute for the eventual benefit/cost evaluation performed in the feasibility study, but rather an approximate "test" for potential system utility. It is, therefore, kept sufficiently optimistic to preclude rejection of a corridor due to possible estimating inaccuracies.

Recognizing that a substantial data base is needed for an IMIS corridor feasibility study, and that data collection can require a considerable expenditure of resources, the second task was geared toward identifying for the user the specific data base required and associated collection and analysis methods to be employed. The approach adopted was to examine the end uses of the data in the methodology and then "backtrack" to identify the basic data requirements. This process, which provides an understanding of why data are being collected and in what form they will be used also serves to avoid any unnecessary data collection. As a further part of this task, estimates were developed, where possible, on data collection costs. Also, alternatives were provided for minimizing the effort if necessary to conserve resources. As an example of the latter, if accident data should be found to be unavailable or difficult

to retrieve, it is suggested that statewide averages, as obtainable from FHWA's annual publication "Fatal and Injury Accident Rates on Federal Aid and Other Highway Systems" be used as a substitute. Another example is the provision of an analytical model to compute ramp-to-ramp origin-destination data which can be used in lieu of a field survey.

The third task, i. e. development of the generalized methodology for performing the feasibility study, represented the major effort of Phase II. The starting point for the development was the work performed and experience gained in the site-specific study accomplished during Phase I. The procedures used there were reviewed, refined, and generalized to form a step-by-step process which could be applied to any corridor. Major steps in the feasibility study process were defined, including such topics as the selection and evaluation of candidate routes, selection of control area boundaries, development of a series of alternative system designs, system cost determination, system benefit determination, and benefit/cost analysis. In each case, guidelines and (where practical) illustrative examples were provided to assist the user in understanding and applying the methodology. Trade-off factors for equipment elements were identified to enable appropriate selections which provide desired functional capability. Typical costs were also provided to serve either as guidelines or as substitute values, if the user elected to bypass the step of obtaining or estimating cost data on his own. In general, the methodology was tailored to incorporate the user's knowledge and experience with the traffic operations in his corridor, and to identify options for reducing the work effort if deemed (by the user) to be appropriate in his case.

The results of the three tasks described above represent the major output of the IMIS Phase II Study. In order to make these results available to using agencies, they have been documented separately in the form of a "Handbook" (see the Documentation Page in this report for the Handbook document number).

Before releasing such a Handbook for general use by the traffic engineering community, it was necessary to "test" it to establish that it does in fact provide a workable methodology. Furthermore, since the benefit evaluation portion of the methodology is predictive in nature, it was necessary to show that the predictions are reasonably accurate.

The above effort represented the final task of the Phase II program. The approaches used, activities performed, and results of the process are the subject of the remainder of this report.

### 1.3 HANDBOOK TESTING AND VALIDATION APPROACH

The approach used to test the "workability" of the Handbook was to actually use it to perform an IMIS feasibility study in a real-world corridor. In this way the total methodology could be exercised for a consistent and realistic set of conditions, thus providing a sound basis for its evaluation. Each step in the methodology was performed in its proper sequence and in accordance with the Handbook procedures. For reference, the Handbook task sequence is shown in Figure 1. If a problem was encountered, the methodology was reviewed and revised as necessary to eliminate the problem. Then, as each step was completed, a "reasonableness" check was performed.

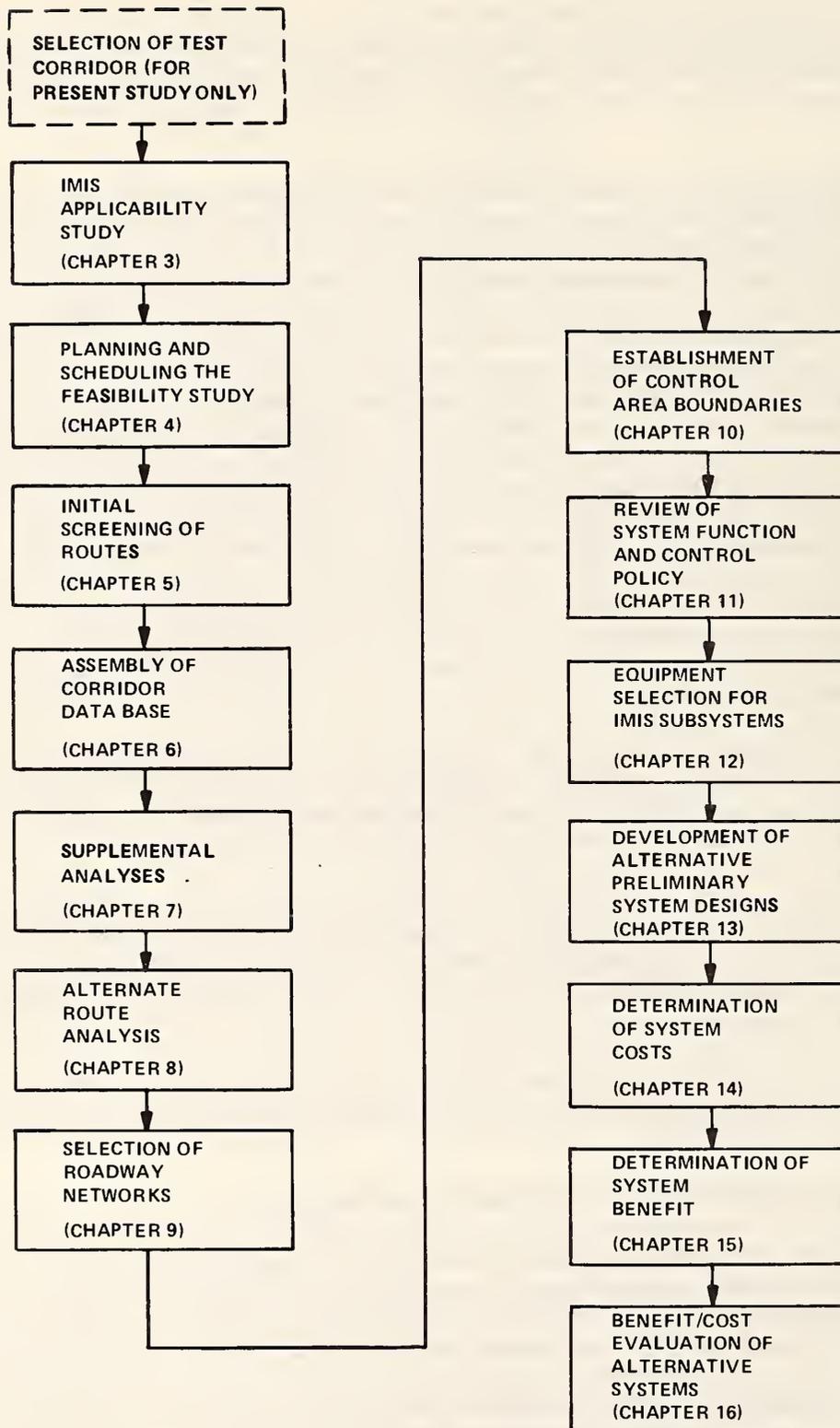


Figure 1. IMIS Feasibility Handbook Task Sequence

Here, as applicable, the outputs were examined to verify that (1) they were plausible, and (2) they displayed a proper input-output sensitivity, e.g., small changes in input would not cause major variations in output. Other hypothetical situations (as might be found in other corridors) were also considered in an attempt to insure the general applicability of the step. For validation of the benefit determination procedures, the approach consisted of using a computer simulation (SCOT model) of a candidate roadway network in the corridor and comparing the benefit parameters thus obtained to those calculated with the Handbook procedures.

As the study progressed it became apparent that certain portions of the Handbook in fact required revision. In these cases, the study was temporarily suspended, the revisions made, and the study continued with the revised methodology. Thus, this report is consistent with, and reflects the application of the final version of the Handbook. As such, it should be a useful adjunct to Handbook users, in that it contains a complete example of a feasibility study performed with the Handbook.

#### 1.4 SUMMARY OF THE HANDBOOK TESTING AND VALIDATION

The initial effort consisted of selecting a "test corridor" to which the methodology would be applied. A series of candidates located throughout the country, was initially defined. Evaluation criteria were then developed, the primary ones being the suitability of the roadway network (to insure an adequate exercising of the methodology), availability of a good data base (to avoid an inordinately large field data collection effort), and a potential need for IMIS (to provide a more credible study). The results of the evaluation led to the selection of a roadway network in California as the test corridor. The corridor extends from the downtown Los Angeles area some 25 miles \* eastward, and includes three major east-west limited access facilities, i.e., the San Bernadino Freeway (I-10), the Pomona Freeway (Cal 60), and the Foothill Freeway (I-210). A map of the roadway network included in the study is contained in Section 2 (Figure 2).

Ordinarily, the next step would consist of the applicability study, which requires only a minimum of data (e.g., typical average speeds, peak period duration). Although it was anticipated that the applicability study would indicate potential feasibility, there was no intention of terminating the study if the reverse was true, since all of the Handbook methodology was to be exercised. Furthermore, even the minimum data base required was not yet available to the staff. Thus, in this particular case, the applicability study was deferred, and the data collection effort was performed next.

For this purpose, members of the study staff visited the test site and met with members of the Freeway Operations Branch of the California Department of Transportation. As a result of the field trip a sufficiently comprehensive data base was compiled to enable the total study to be performed. The staff also collected field data, including some special purpose parameters required for later use in calibrating the simulation model to the test corridor.

The three-step applicability study (described earlier) was performed next. As anticipated, the results indicated that IMIS had the potential to be cost effective in the test corridor. A "maximum possible" benefit/cost ratio of 4.43 was calculated

\*1 mi=1.61 km

(assumes IMIS can eliminate all delay), as was an "expected" benefit/cost ratio of 2.38 (a more realistic estimate based only a portion of the delay being eliminated). These calculations are based on implementing a complete system for the entire corridor. Higher benefit/cost ratios may be achievable for other alternative designs which have smaller roadway networks or reduced equipment complements.

At this point in the methodology, a using agency would perform the task of planning and scheduling the feasibility study. In the present case, this effort had already been planned and scheduled under the Phase II contract. An estimate was made, however, based on the effort expended by the staff (appropriately adjusted) that a typical feasibility study would require on the order of 1 man-year of effort over a 4 to 6 month period, if a reasonably good data base was available.

The next task, actually the technical start of the feasibility study, was the initial screening of the roadway network to determine whether any routes or route segments should be eliminated because of their lack of utility or other known problems. The purpose here is to avoid data collection and analysis for these cases. The criteria used are primarily qualitative, and user knowledge and judgment play an important role in their application. Based on the data collected and discussions held during the field trip, the staff completed the screening task. Several routes and segments were eliminated. Major reasons were (1) availability of a better route nearby, (2) connectivity aspects, and (3) overall utility for diversion purposes. The output of this task was a baseline corridor map, showing all candidate routes remaining in the roadway network. (The map is shown in Figure 3, Section 5.)

The data collection effort was discussed previously. Data reduction consisted primarily of tabulating and cataloging the collected information. The two major analysis aspects performed under this task were the development of balanced flow network diagrams for the limited access facilities and hourly volume variations for a typical weekday. (Typical samples are given in Figures 5 and 6, Section 6.)

A series of supplemental analyses was then performed in accordance with the Handbook procedures. These analyses were geared toward providing additional information required for subsequent tasks, and included development of the following:

- Control probability model coefficients\*
- Accident/incident rates for limited access facilities
- Capacity analysis of the alternate routes
- Origin-destination pattern (freeway ramp-to-ramp)
- Median trip length

-----  
\*The control probability model is used in the system evaluation to account for the dynamic nature of traffic and the ability of IMIS to respond to it. In essence, it provides the fraction of time that a given control policy can be used to obtain positive benefits. The model coefficients represent a measure of traffic variability in the form of the mean and standard deviation of a set of traffic volumes.

The results of these analyses are contained in Section 7. Median trip length on the freeway (distance travelled by at least 50 percent of the motorists) was found to be on the order of 4 miles (6.14 kilometers). A minor modification was made to the handbook to simplify the trip length computation.

Next, the alternate routes were ranked relative to each other based on the primary route or routes that they serve. The Handbook provides the criteria and quantitative factors for the ranking process. The results of the ranking (contained in Section 8) provide guidance in developing the alternative system designs. It is noted that a fairly extensive revision was made to the Handbook chapter on the alternate route analysis (ranking process) as a result of this study. It was found that the procedures, which appeared to work reasonably well for the simple example case presented, were somewhat inadequate for more complex cases. The real-world application served to uncover this problem, and the procedures were appropriately modified.

The next sequential step in methodology consisted of developing the roadway network configurations which provide a subsequent basis for establishing the series of alternative system designs. Inputs to the process include various data elements (e.g. average speeds, travel times, capacity, congestion locations), the alternate route rankings, and, of course, judgment. A major objective is to develop configurations with significant variations in roadway networks so that the alternative designs will reflect a broad spectrum of cost and functional capability. In the present study, four configurations were defined. The first included all of the candidate roadways remaining after the initial screening process. This represents a "maximum" system and serves to provide an indication of the potential investment and benefits associated with a full corridor implementation. The remaining three configurations were defined as progressively smaller subsets of the first. In one case, the upper western corner of the corridor was deleted, along with a low-ranked alternate route and an associated connector. Next, the entire upper half of the corridor was eliminated, primarily because of its minimal congestion problems. Finally, the eastern half of remaining network was excluded for a similar reason. (The four network configurations are illustrated in Figures 10 thru 13, Section 9).

The network configurations were next partitioned into subnetworks to establish control area boundaries. Each subnetwork represents a segment of the corridor where a common control philosophy may be applied. For example, one type of subnetwork consists of a single freeway with a service road or parallel arterial. The primary control function associated with this type of subnetwork is ramp metering, in conjunction with computer control of the signals on the service road or arterial. (While diversion from the freeway is also possible, in this case it is presumed that the available capacity will be used primarily for vehicles diverting from entrance ramps. Thus, diversion is not considered a primary control function for this type of subnetwork). As a result of the present study, some revisions were made to related section of the Handbook for clarification of the subnetwork definition procedure. As an additional output of this task, control probabilities (mentioned earlier) were assigned to each subnetwork type in accordance with the Handbook guidelines. These values are required for later use in the system evaluations.

At this point in the study, a review of system function and control policy is normally accomplished by the using agency, to determine whether there are any special factors to be considered in the development of the alternative designs (e.g., interface with existing surveillance and control systems, jurisdictional preferences or constraints, etc.). For the purposes of the present study, it was assumed that any such factors would not exert a significant influence on the designs.

The system designs were then addressed. In accordance with the Handbook methodology, the initial effort consisted of the selection of typical equipment and the development of associated unit cost data. Then, the alternative designs were configured. Two designs were developed for each roadway configuration defined earlier. One design included a maximum equipment complement, the other a minimum equipment complement. The equipment and roadway combinations thus yield a total of eight candidate systems. Table 1 (a reproduction of Table 35) provides a quantitative summary of the candidate designs. In the table, Network A represents the largest roadway network, Network D the smallest. The "1" and "2" designations refer to the maximum and minimum equipment complements, respectively. (Note that in the "2" configurations, highway advisory radio is used to replace many of the variable message signs, thus the increased number.) All designs are based on an owned cable as the communications medium, with polled time-division multiplexing and a high degree of local data processing.

The next steps in the methodology consist of the development of system costs, benefits, and subsequently, benefit/cost ratios. The results of performing these steps for the test corridor are summarized in Table 2. It is seen that all systems provide a benefit/cost ratio greater than 1; however the two systems based on the smallest roadway network (Network D) provided the highest benefit/cost ratios.

Benefit/cost ratio as a relative evaluation measure seeks to obtain the maximum return on an investment. The Handbook suggest another measure, as well, i.e., the incremental benefit/cost ratio. This allows a second philosophy to be considered, this being that further investment (up to any cost constraint) is warranted as long as the additional benefits accrued continue to exceed the additional cost. To answer the feasibility question, the first measure is adequate. To select a candidate design, both are useful. (It is interesting to note that on the basis of the incremental benefit/cost ratio, Candidate A2 would be rated "best"). A final candidate selection, however, must also be based on judgment, with due consideration to the corridor needs and the functional capability provided by the candidates.

The final portion of the evaluation methodology consists of a benefit/cost sensitivity analyses. The purpose here is to provide an indication of the potential range in benefit/cost ratio due to uncertainties in major factors used in the cost and benefit computations. The sensitivity analysis is most important for cases where the benefit/cost ratio is close to 1.0. The analysis was therefore performed for the A2 system ( $B/C = 1.66$ ), and the resulting variation was found to be  $\pm 0.5$ . Thus, the benefit/cost ratio for the A2 system could range from 1.16 to 2.16.

The above completed the application of the feasibility study methodology to the test corridor. One additional task remained in Phase II, that being the verification of the basic benefit determination procedure contained in the Handbook,

Table 1. System Design Summary

Subsystem	Equipment Complement	Candidate Designs							
		Network A		Network B		Network C		Network D	
		A1	A2	B1	B2	C1	C2	D1	D2
Diversion/Motorist Advisory	Visual Sign Loc. (#)	49	17	35	15	27	10	16	6
	Hwy Adv Radio Loc. (#)	15	36	12	27	10	22	7	13
Ramp Metering	Metering Stations (#)	97	97	70	70	64	64	64	64
Arterial Control	CIC Intersection (#)	13	13	9	9	7	7	6	6
	Non-CIC Int. (#)	126	126	86	86	51	51	33	33
Surveillance	Freeway Det. Spacing (Miles)	1/2	1	1/2	1	1/2	1	1/2	1
	Arterial Det. Sta. (#) (Non-CIC)	252	252	172	172	102	102	66	66
Communications	Cabinet Loc. (#)	1,091	878	860	688	606	485	329	265
	Computers (#)	2	1	2	1	2	1	2	1
Control Center	Coverage (%)	100	50	100	50	100	50	100	50
	Stations (#)	Existing							
Motorist Aid	Inclusion	YES	NO	YES	NO	YES	NO	YES	NO
	Police Cars (#)	Existing							
Pre-Trip Information Serv.	Tow Trucks (#)	Existing							

Note: 1 mile = 1.61 Km.

Table 2. Evaluation Summary for Alternative System Designs

Candidate System	Equivalent Annual Cost (\$ Millions)	Annual Benefits (\$ Millions)	Benefit/Cost Ratio
A1	5.577	8.474	1.52
A2	4.493	7.445	1.66
B1	4.385	6.451	1.47
B2	3.586	5.775	1.61
C1	3.345	5.405	1.62
C2	2.633	4.831	1.83
D1	2.270	4.676	2.06
D2	1.723	4.097	2.38

through computer simulation. The SCOT model, developed under FHWA sponsorship was used for this purpose.

It should be noted that the basic benefit relationships developed for the Handbook were based on an extensive series of computer runs (approximately 150) performed during the Phase I study. Thus, the present objective was to develop a parametric set of check points to ascertain that the relationships could be applied to any corridor, i.e., that they were not heavily site-specific.

Since the entire test corridor could not be accommodated in the SCOT model without extensive over simplification, the "D" candidate roadway network configuration was used for the validation. The SCOT model was modified to increase the vehicle handling capability so that the high volumes in this network could be accommodated without compromising the fidelity of the simulation. Special data collected during the field trip were used to calibrate the model to the test corridor.

A series of computer runs was made, including baseline (no control) and control runs for several congestion and incident scenarios. The computer results were then compared to the methodology results on a statistical basis. It was found that the observed differences could not be shown to be statistically significant. The methodology is therefore considered to be sufficiently accurate for general use in a feasibility study.

The overall conclusion for the study is that the Handbook (as revised through its application to the test corridor) is a viable tool for establishing the feasibility of IMIS in any corridor. It provides a sequential procedure for addressing all of the facets of IMIS, starting with a basic applicability study, and proceeding through the data requirements, analyses, configurational aspects, and finally, the evaluation of alternative systems designs. The Handbook does not and cannot reduce an IMIS feasibility study to a simple mechanical process, since the judgment of the user must be an essential ingredient if the results are to be meaningful. Thus, though guidelines and examples are included where possible, the methodology permits, and in fact urges, the user to exercise this judgment.

Finally, it should be recognized that the primary objective of the present study was to "test" the Handbook. As such, it should not be construed as a formal

verification of IMIS feasibility in the test corridor. Nevertheless, the study was quite comprehensive, and it is felt that the results are at least indicative of a high potential for IMIS to in fact be feasible there.

## 1.5 REPORT ORGANIZATION

The report is organized as follows: Section 2 discusses the selection of the corridor used for the study. Sections 3 through 16 present the results of applying the (revised) Handbook methodology to the test corridor. For cross-referencing purposes, these sections have been numbered to have direct correspondence with the related chapters in the Handbook. In addition, equations used in this report which appear in the Handbook have been assigned the Handbook equation numbers. Section 17 presents the study conclusions. The results of the simulation work for benefit validation are contained in Appendix A.

In preparing this report, an attempt was made to make it a "stand-alone" document by incorporating descriptive material regarding the Handbook procedures being applied in each step. Inclusion of all of the Handbook detail was obviously not practical since this would have required a major duplication of Handbook material in this report. Therefore, if further detail is of interest, it is suggested that a copy of the Handbook be obtained as a reference.

## SECTION 2

### SELECTION OF TEST CORRIDOR

The initial step in the selection of the test corridor consisted of developing a list of sites which appeared to be reasonable candidates for IMIS. The list was developed in group discussions, based on general familiarity with the locations, overall geometric characteristics, and expected data base availability. Table 3 summarizes the set of candidate corridors established.

The next step in the process consisted of developing the selection criteria. Basically, three criteria evolved as being of primary importance:

- Suitability of roadway network - Since the objective was to test the methodology to the fullest extent possible, use of a minimum or oversimplified network was deemed undesirable. Instead, the network should contain a reasonable number of parallel roadways and connectors to provide sufficient candidates for exercising the aspects of route evaluation, development of alternative designs with varying network configurations, and benefit determination.
- Availability of existing data - Selection of a corridor for which a substantial portion of the required data base was not available would result in an inordinately large field data collection effort by the study staff. From both a time and economic viewpoint, this was beyond the scope of the study. The existence of a good available data base was therefore necessary. Furthermore, the methodology utilizes standard traffic engineering parameters, collected by standard techniques; thus, the data collection per se, does not require validation.
- A potential need for IMIS - There should be evidence of recurrent congestion in at least portions of the corridor. If this is not the case, it is likely that the applicability study would indicate negative results (IMIS not warranted). While the feasibility study methodology could still be exercised, it would undoubtedly represent a poorer and less rigorous test. For example, since benefits would be minimal, the validation of the benefit methodology through simulation would tend toward a trivial test. (Carried to the extreme, if there were zero benefits determined by the methodology, and verified by simulation, this would hardly be a test of the benefit determination procedures.)

While the above represented the primary corridor selection criteria, two other factors were also considered. One was the overall corridor size. Although the Handbook indicates that an IMIS corridor may be as short as 5 miles (8 kilometers) in length, a short corridor was deemed undesirable in that it would limit the ability to configure alternative designs. On the other hand, an unduly long corridor could impose an unwarranted excessive drain on the available study resources. Although

Table 3. Candidate Corridors for Methodology Validation

CORRIDOR	CHARACTERISTICS OF CORRIDOR						EXPECTED DATA AVAILABILITY				COMMENTS		
	Length Mi	Width Mi	Lim Acc	Svce Rd	Par Art	Conn	Ntwk Cmplx	Geom	Vol	T, T, Spd		Int	Acc
1. Harbor Freeway Los Angeles, California	10-12	2-3	1	Part	4	5	Simple Rect	Yes	Yes	Yes	Unkn pbly yes	Yes	Operational Ramp meter- ing system. Part of 42 mile project
2. North Central Expwy Dallas, Texas	12-14	3-5	1	Yes	4-6	6	Rect DGLG, Diag Roads	Yes	Yes	Yes	Yes	Yes	Operational corridor system
3. I-95/US441 Miami, Fla.	10-12	3-5	1	No	5-6	8-9	Simple Rect. Us 1 diag	Yes	Yes	Unkn	Yes	Yes	Initial corridor studies performed. Signal control system being installed (CBD)
4. I-80/Rt 46 Northern N. J.	14-16	2-4	1	No	1	3	Complex 'S' Shape	Yes	Unkn	Yes	Yes but scat- tered	Yes	Corridor study in progress
5. Eisenhower Expwy Chicago, Illinois	14-16	2	1	Part	2	4	Simple Rect	Yes	Yes	Yes	Unkn pbly yes	Yes	Operational ramp meter- ing system
6. Gulf Freeway Houston, Texas	10	2	1	Part	0	0	Simple Rect	Yes	Yes	Yes	Unkn	Yes	Operational freeway system
7. I-10 New Orleans, La.	8-10	2	1	No	2	6	Simple Rect	Yes	Unkn pbly yes	Unkn	Unkn	Unkn pbly yes	Signal control system being installed (CBD)
8. I-5/US101 Los Angeles, Cal.	14-16	2-4	2	No	2	4	Complex Rect, Diag Conn	Yes	Yes	Yes	Unkn pbly yes	Yes	Operational freeway system. Research facility discontinued
9. John Lodge Freeway Detroit, Mich.	6-8	1-2	1	Part	1	4	Complex 'S' Shape	Yes	Yes	Yes	Unkn	Yes	Operational freeway system. Research facility discontinued
10. I-10/Cal 60 Los Angeles, Cal.	20	3-5	2	No	3	6	Rect 'S' Shape	Yes	Yes	Yes	Unkn pbly yes	Yes	I-10 has operational busway

Note: 1 mile = 1.61 km

Svce Rd - Service Road  
 Rect - rectangular  
 Geom - geometry  
 Int - intersection  
 Lim Acc - limited access roadway  
 DGLG - dog leg  
 Vol - Volume  
 Part - Partial  
 Diag - diagonal  
 TT - travel time  
 Lim Acc - Unknown  
 Prbl - probably  
 Par. Art - parallel arterial  
 Ntwk - network  
 Spd - speed  
 Acc - accident  
 Conn - connector

hard limits were not set, it was subsequently decided that a 15 to 25 mile (24 to 40 km) corridor length would best suit the overall objectives of the study. The second factor was whether or not the corridor had some form of surveillance and control system already installed. If so, this was considered to be the less desirable case, primarily because the methodology would then be applied for an incremental design and would not be as fully tested as for a corridor free of such influences.

The final step in the selection process was the evaluation of the candidate corridors based on the above-noted criteria. Preliminary data sources included available maps, published reports, and the staff's experience and familiarity with many of the corridors. This proved adequate to identify the most promising candidates. For these cases, the cognizant jurisdictions were then contacted to establish the extent of the available data and verify the potential need for IMIS. (It is noted that an additional corridor, the I-5/I-405 corridor in Seattle, Washington, was added to the primary candidate list during the evaluation).

The results of these investigations, coupled with suggestions from the FHWA led to the recommendation of the I-10/Cal 60 corridor in California as the test site. The corridor was subsequently expanded to include an additional freeway, I-210, as well. Figure 2 depicts the corridor, approximately to scale, and shows the candidate roadway network included for study purposes. The site recommendation was based on the excellent data base available, the "richness" of the roadway network, and the existence of recurrent congestion in portions of the corridor. Overall corridor size and the absence of existing surveillance and control were additional favorable factors. The recommendation was discussed with the FHWA Contract Manager and subsequently approved for use in the study.

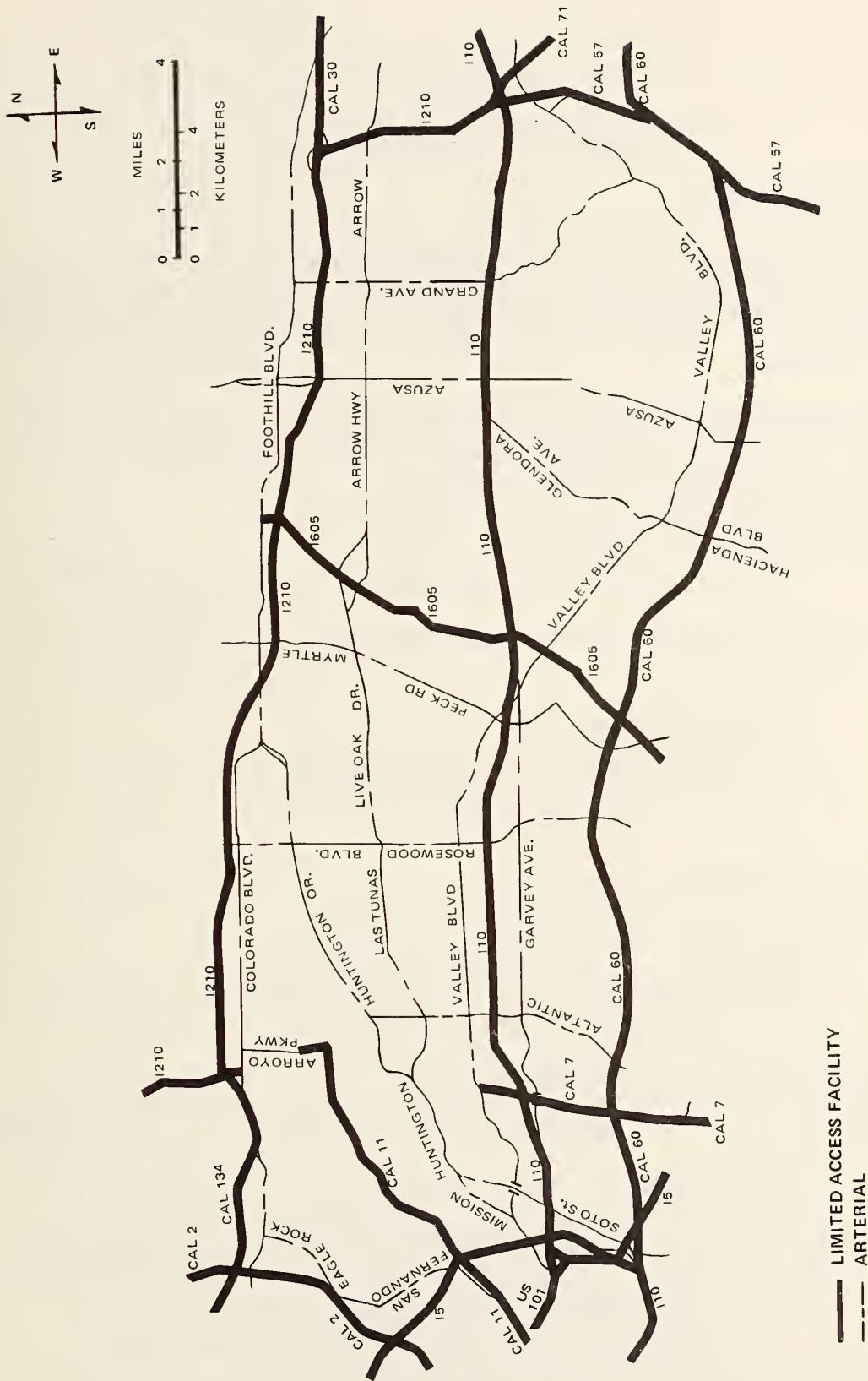


Figure 2. The Test Corridor

## SECTION 3

### IMIS APPLICABILITY STUDY

#### 3.1 INTRODUCTION

This section describes the IMIS applicability study as performed for the test corridor in California. In general, the purpose of this initial step of the methodology is to determine, with a minimum expenditure of resources, whether IMIS has the potential to be cost-effective in a given corridor. If so, the feasibility study would be conducted.

The application of this part of the methodology to the test corridor follows the procedures given in the corresponding chapter of the Handbook.

#### 3.2 APPLICATION OF THE QUALITATIVE GUIDELINES

The characteristics of the test corridor relative to the seven qualitative guidelines contained in the Handbook are listed below.

- Limited Access Facilities Running the Length of the Corridor (Primary Roadways):

I-10 (San Bernadino Fwy)  
Cal 60 (Pamona Fwy)  
I-210 (Foothill Fwy)

(A minimum of 1 is required)

- Parallel Alternate Facilities:

Garvey Ave.  
Valley Blvd.  
Mission Rd/Huntington Dr/Las Tunas Dr/Live Oak Ave/Arrow Hwy  
Colorado Blvd/Huntington Dr/Foothill Blvd.

(A minimum of 1 is required)

- Corridor Geometry - Length to Width Relationship

Overall Corridor

Length to width ratio (L/W) is approximately 3

Primary Roadway Pairs

- (a) I-10 and Cal 60, L/W ranges from 8 to 12
- (b) I-10 and I-210, L/W ranges from 5 to 8

(A length substantially greater than width, i.e., distance between parallel facilities, is required)

- Corridor Length:

Approximately 24 miles (39 km)

(A minimum length of 5 miles (8 km) is required)

- Connector Routes:

The corridor contains 11 connector routes. The average spacing is thus 2.2 miles (3.5 km)

(A connector at least every 5 miles (8 km) is required).

- Corridor Termini:

Eastern End - I-210 and Cal 57 connect all primary routes

Mid-Point - I-605 connects all parallel routes

Western End - I-5 and US 101 connect I-10 and Cal 60 via a freeway "mixing bowl"

I-5 and Cal 2 connect I-10 and I-210/Cal 134

(Well defined termini are required)

- Primary Route Recurrent Congestion:

West of I-605

Cal 60 congestion duration 1-1.5 hrs.

I-10 congestion duration 1-1.5 hrs.

I-210 congestion duration 0.5-1 hr.

East of I-605

Cal 60 congestion duration of 1 hr. in vicinity of I-605 only

I-10 congestion duration of 0.5 hr. in vicinity of I-605 only

I-210 minimal congestion

(Minimum of .5 hours on a primary route is required).

A comparison of the test corridor characteristics with the guidelines (indicated in parentheses) indicates that the corridor possesses the necessary general characteristics.

### 3.3 THE "MAXIMUM POSSIBLE" BENEFIT/COST CALCULATION

The data required for the maximum possible benefit/cost calculation, i.e., the one which assumes IMIS can eliminate all of the existing delay, are as follows:

MI, the number of miles in each congested section

LNS, the number of lanes in each congested section

$U_c$ , the average speed in each congested section  
 $U_{ff}$ , the free flow speed, assumed to be 55 mph (88.5 kph)  
 $Q_i$ , the flow rate in each congested section (vehicles/lane/hr)  
 $T_c$ , the duration of congestion including both AM and PM peak periods

The above data are used in the delay computations via the following formulas, as contained in the Handbook:

$$Dss_i = Q_i \frac{(U_{ff} - U_c)}{U_{ff}U_c} \quad (1)$$

where  $Dss_i$  = the delay in veh-hrs/lane mile/hr (1 veh-hr/lane mile/hr = 0.62 veh-hr/lane km/hr) in congested section i

and  $DT_i = Dss_i \cdot LM_i \cdot Tc_i \quad (2)$

where  $DT_i$  = daily vehicle hours of delay in section i

$LM_i$  = the number of lane miles (1 lane mile = 1.6 lane km) in section i, that is, the product of LNS and MI.

The total annual delay is then computed by multiplying the  $DT_i$  by the number of days of recurrent congestion per year, and summing the results for each section.

Table 4 presents the data used and the results of the annual congestion delay computation. The values were derived from the data obtained for the test corridor. The overall delay was found to be 1,833,718 vehicle-hours.

Following the handbook methodology, the delay due to accidents and incidents is next estimated, and is taken as being equal to the congestion delay. The total annual delay is then the sum of both components, or

$$\text{Total delay} = 3,667,436 \text{ vehicle hours}$$

The monetary equivalent of the delay saving benefit is taken as \$4.00/veh.hr, which includes both the value of time and value of fuel saved. Thus, the total monetary benefit is

$$\$4 \times 3,667,436 = \$14,670,000$$

Assessing the test corridor as being one of relatively high complexity, the estimated system capital cost is taken as \$1 million per mile (\$0.621 million per Km) of corridor length, per the Handbook guideline. Therefore, the total capital cost is \$24 million. On an equivalent annual basis, assuming a 15 year life cycle and 10 percent rate, this value becomes:

$$\text{Capital Cost} - \$3.155 \text{ million (equivalent annual)}$$

Table 4. Annual Delay Caused by Congestion

Roadway Segment	LNS	MI	Q	Tc	Uc	Dss	DT
<u>Cal 60</u>							
I-5/101 to Cal 7	5	3	1700	3.0	27.5	30.9	361530
Cal 7 to I-605	4	8.6	1875	2.0	35.0	19.5	348816
East of I-605	4	2.0	1600	2.5	27.5	29.1	148294
<u>I-10</u>							
I-5/101 to Cal 7	6	2.5	1500	3.0	30	22.7	265590
Cal 7 to I-605	4	9.6	1625	2.5	40	11.1	277056
East of I-605	4	2.0	1800	2.0	40	12.3	51168
<u>I-210</u>							
C134/C7/I-210 to Rosemead	5	4.9	1500	2.0	35	15.6	198744
Rosemead to I-605	4	4.5	1875	2.0	35	19.5	182520
East of I-605	4	-	-	-	-	-	(Negl.)
Total						1,833,718	

Annual maintenance and operating costs are taken as 5 percent of the above, or 0.158 million. The total system cost (equivalent annual) is then:

Total cost - 3.313 million

The theoretical benefit/cost ratio is computed as

$$\frac{\$14.670 \text{ million}}{\$ 3.313 \text{ million}} = 4.43$$

The above result is a positive one, and indicates that the next step of the applicability test should be performed.

### 3.4 THE "EXPECTED" BENEFIT/COST RATIO

The first step in this calculation is a revised computation of congestion delay saved using the following equation:

$$\frac{\Delta D_{s_i}}{D_{ss_i}} = \Delta_{D/Q} \cdot \Delta Q_i / Q_i \quad (3)$$

where

$\Delta Ds_i$  = the estimate of actual delay saved

$\Delta Q_i$  = the estimated volume per lane divertible to an alternate from section i

$\Delta_{D/Q}$  = the sensitivity coefficient of delay saved to volume diverted.  
A derived value of this parameter is 4.5

The value of  $\Delta Ds_i$  is then used in place of  $Dssi$  in the remaining computations as were performed for the "maximum possible" case. The results are summarized in Table 5. The values of  $\Delta Q$  were obtained using the guidelines provided in the Handbook.

The remaining steps follow the computations performed for the "maximum possible" case, and the results are summarized below:

- Accident Delay Saved = 984,770 vehicle hrs/yr
- Total Delay Saved = 1,969,540 vehicle hrs/yr
- Total Annual Benefit = \$7.878 million
- Total Equivalent Annual Cost = 3.313 million
- Benefit/Cost Ratio = 2.38

The results of this test are again positive, and indicate that the feasibility study should be conducted.

Table 5. Delay Saved with Control

Roadway Segment	$D_T$	$\Delta Q$	Q	DTS
<u>Cal 60</u>				
I-5/101 to Cal 7	361530	150	1700	143549
Cal 7 to I-605	348816	350	1875	293005
East of I-605	148294	150	1600	62562
<u>I-10</u>				
I-5/101 to Cal 7	265590	150	1500	119516
Cal 7 to I-605	277056	250	1625	191808
East of I-605	51168	150	1800	19188
<u>I-210</u>				
C134/C7/I210 to Rosemead	198744	150	1500	89435
Rosemead to I-605	182520	150	1875	65707
			Total	984,770

## SECTION 4

### PLANNING AND SCHEDULING THE FEASIBILITY STUDY

The effort and resources required to perform an IMIS feasibility study can vary widely from one corridor to the next. The major factors which cause this variability include:

- The differences in overall size of the corridor and the roadway networks included
- The availability of the required data (a major factor)
- The extent to which local knowledge and judgment are substituted for more rigorous procedures.

The planning and scheduling of the study is thus an important initial step in the methodology which must be performed to identify the potential levels of effort required, and permit the feasibility study to be tailored to fit the available resources.

This step was not specifically performed as part of the methodology validation task, per se, since this work was already planned and scheduled as part of contract effort for Phase II. Furthermore, a planning and scheduling task, in itself, is not one which is subject to validation. One can only judge, in retrospect, how well the job was done.

In addition, the effort planned or actually expended by the study staff would not really serve as a reasonable user guideline for the following reasons:

- Although a feasibility study was performed, the primary objective was to test the methodology. Thus, the corresponding efforts could vary widely.
- The experience gained in Phase I and in developing the Handbook during Phase II enabled the staff to apply the methodology much more quickly than a non-familiar user.
- The staff did not possess the intimate working knowledge of the corridor that a using agency could apply. Thus, maximum use was made of the Handbook alternatives when not crucial to the methodology validation. For example, the typical cost data in the Handbook were used; a user might spend the time to verify their applicability and/or obtain cost data on his own.

In an attempt to provide some indication of the effort involved in a typical feasibility study, the methodology steps were reviewed and assigned nominal levels of effort. On this basis it is estimated that, if a reasonably good data base is available, performance of the study will require on the order of 12 man-months of effort (approximately 60 percent professional, 40 percent other technical personnel), and 4 to 6 calendar months.

## SECTION 5

### INITIAL SCREENING OF ROUTES

In this section the initial route screening process is applied to the test corridor. The process consists of developing a preliminary list of roadways which might be included in one or more of the system configurations, and then performing a qualitative evaluation of these roadways. In general, the basic purpose of the process is to avoid extensive data collection and analysis efforts for routes, which after brief review, can be excluded as candidates because of their lack of utility or because they pose certain other problems.

Ordinarily, this task would be performed by personnel in the using agency, based on their intimate knowledge of traffic operations and other corridor characteristics. In the present case, the study staff made use of the information obtained during the field trip to the test site.

Based on the information collected, a list of corridor roadways to be considered in the study was developed. These are indicated in Table 6.

For the next step (qualitative evaluation), the criteria noted in the Handbook were applied to each of the roadways. The results of this process are summarized in Table 7. It should be noted that the study staff was not in a position to assess jurisdictional or other problem areas, and these were not considered in the evaluation. Thus, the major reasons for eliminating roadways in this corridor were the availability of a better route nearby, connectivity aspects, and overall utility for diversion.

Figure 3 illustrates the list of roadways considered in the test corridor. The roadways retained as a result of the qualitative evaluation are shown with heavier lines. This figure now serves as the corridor map for the remainder of the study.

Table 6. Preliminary List of Corridor Roadways

A. Facilities in Direction of Corridor

Limited Access

Cal 60	Pomona Fwy
I-10	San Bernadino Fwy
I-210/Cal 134	Foothill Fwy/Ventura Fwy

Arterial

Garvey Ave.  
 Valley Blvd.  
 Colorado/Foothill Blvd.  
 Mission/Huntington/Las Tunas/Live Oak/Arrow

B. Connector Routes

Limited Access

I-5/Cal 2	Golden State/Glendale
Cal 7	Long Beach Fwy
I-5/Cal 11	Golden State/Pasadena/Arroyo Pkwy
I-605	San Gabriel River Fwy
Cal 57/I-210	Orange/Foothill

Arterial

San Fernando/Eagle Rock  
 Soto/Huntington  
 Atlantic  
 Rosemead Blvd.  
 Peck/Myrtle  
 Hacienda/Glendoria Ave.  
 Azusa Ave.  
 Grand Ave.

C. Boundaries of Corridor

Northern - I-210/CAL134	Foothill/Ventura Fwy
Western - US 101/I-5/Cal 2	
Southern - Cal 60	Pomona Fwy
Eastern - I-210/Cal 57	

Table 7. Preliminary Assessment Chart\*

Corridor Route	Route Segment		Proximity To Main Corridor Routes	Destinations	Connectivity	Driving Quality	Impact On Adjoining Land Use	Jurisdiction	Availability Of Better Routes	Route Or Segment Eliminated
	From	To								
I-10 - San Bernadino Freeway	I-10/I-5 I-605	I-605 I-210/Cal 57	Excellent Excellent	Excellent Good	Excellent Good	Excellent Excellent	None None	State State	No No	
Cal 60 - Pomona Freeway	I-10/I-5 I-605	I-605 Cal 57	Excellent Good	Excellent Good	Excellent Good	Excellent Excellent	None None	State State	No No	
Cal 134/I-210 - Ventura Foothill Fwy	Cal 2 I-210/Cal 7 I-605	I-210/Cal 7 I-605 Cal 30	Fair Fair Good	Fair Fair Good	Fair Fair Good	Excellent Excellent	None None None	State State State	No No No	
Garvey Avenue	I-10 Atlantic	Atlantic Valley/I-10	Good Good	Fair Fair	Fair Good	Fair Good	Some Some	Local Local	No No	
Valley Boulevard - Mission Road	I-10/I-5 Cal 7 Peck/I-605	Cal 7 Peck/I-605 I-210/Cal 57	Good Good Good	Fair Fair Fair	Good Good Fair	Fair Good Good	None None None	Local Local Local	No No No	
Colorado - Foothill Boulevard	Cal 2 Cal 134 I-605	Cal 134 I-605 Cal 30	Fair Fair Good	Fair Fair Fair	Poor Fair Good	Fair Fair Good	Some Some Some	Local Local Local	No No No	X
Mission, Huntington, Las Tunas, Live Oak, Arrow	I-10/I-5 Main I-605	Main I-605 I-210	Fair Fair Fair	Fair Fair Fair	Fair Fair Fair	Good Good Good	None Some Some	Local Local Local	No No No	
CONNECTIONS										
I-5/Cal 2 Golden State/Glendale	I-10/Cal 60 I-10	I-10 Cal 134	Excellent Fair	Excellent Fair	Excellent Good	Good Good	None None	State State	No No	
I-5/Cal 11 Golden State/Pasadena/Arroyo	I-10/Cal 60 I-10	I-10 I-210/Colorado	Excellent Fair	Excellent Poor	Excellent Poor	Good Fair	None Some	State State/Local	Yes Yes	X X
Cal 7 - Long Beach Fwy	Cal 60	Valley	Excellent	Excellent	Good	Excellent	None	State	No	
I-605/San Gabriel River Fwy	Cal 60	I-210	Excellent	Excellent	Excellent	Excellent	None	State	No	
Cal 57/I-210 Orange/Foothill	Cal 60	I-210/Cal 30	Excellent	Excellent	Excellent	Excellent	None	State	No	
San Fernando/Eagle Rock	Cal 11/I-5	Colorado Blvd.	Fair	Poor	Fair	Fair	Some	Local	Yes	X
Soto/Huntington	I-5/I-10/Cal 60 Huntington/Main	Huntington/Main Colorado	Good Good	Good Good	Good Good	Fair Good	Some None	Local Local	No No	

\*Assessment represents the views of the study staff, and not those of the California Department of Transportation or the FHWA.

Table 7. Preliminary Assessment Chart\*(Continued)

Corridor Route	Route Segment		Proximity To Main Corridor Routes	Destinations	Connectivity	Driving Quality	Impact On Adjoining Land Use	Jurisdiction	Availability Of Better Routes	Route Or Segment Eliminated
	From	To								
Atlantic	Cal 60	Garvey	Good	Fair	Fair	Fair	Some	Local	Yes	X
	I-10	Huntington	Fair	Poor	Poor	Fair	Some	Local	Yes	X
	Garvey	I-10	Good	Fair	Fair	Fair	Some	Local	No	
Rosemead	Cal 60	Valley	Good	Good	Good	Good	None	State	No	
	Valley	I-210	Fair	Fair	Fair	Fair	Some	State	Yes	X
Peck/Myrtle	Cal 60	Valley	Good	Fair	Fair	Fair	Some	Local	Yes	X
	Valley	I-210	Good	Fair	Fair	Fair	Some	Local	Yes	X
Hacienda/Glendorra	Cal 60	Valley	Fair	Fair	Fair	Fair	None	Local	No	
	Valley	I-10	Fair	Poor	Poor	Fair	Some	Local	No	X
Azusa Avenue	Cal 60	I-10	Fair	Poor	Poor	Fair	Some	Local	No	X
	I-10	I-210	Fair	Good	Good	Fair	Some	State	No	
Grand Avenue	Cal 60	I-10	Fair	Poor	Poor	Fair	Some	Local	Yes	X
	I-10	I-210	Fair	Fair	Fair	Fair	Some	Local	Yes	X

\* Assessment represent the views of the study staff, and not those of the California Dept. of Transportation or the FHWA.



## SECTION 6

### ASSEMBLY OF CORRIDOR DATA BASE

Figure 4 (repeated from the Handbook) summarizes the basic data requirements for performing an IMIS feasibility study. As an aid to understanding why the specific data are needed, the figure also traces the basic requirements through the end uses in the methodology. The Handbook provides a more detailed discussion of the data types, collection and analysis methods, costs, and alternatives.

The data base for the test corridor was assembled by staff members during a field trip to the site. Initially, the staff members contacted personnel from the Freeway Operations Branch of the California Department of Transportation. Their cooperation was excellent, both in providing data and in establishing contacts between the field team and other data source agencies and personnel.

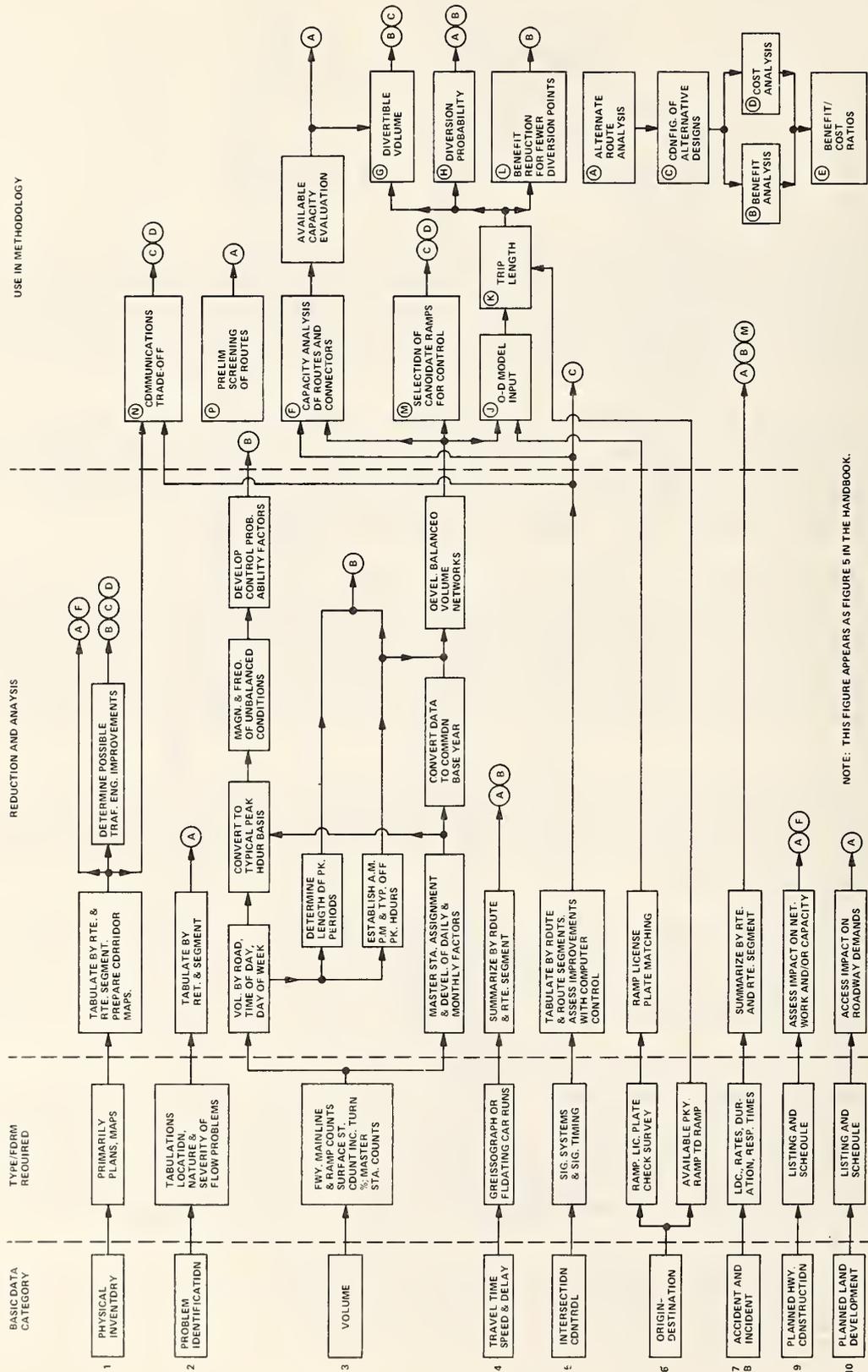
The field team also drove all of the roadways in the corridor, annotating maps with pertinent characteristics and performing floating car travel time studies. In addition, the team collected special data, not required for the feasibility study, but necessary for calibrating the simulation to the test corridor. These special data, collected at sample locations, included speed-volume data for freeway flow, intersection discharge headways, ramp merge delays, and free flow speeds on arterials.

Table 8 lists the various data elements and the corresponding data sources. As a result of the field trip, plus subsequent telephone conversations with Cal DOT personnel, sufficient data were acquired for the purpose of exercising the methodology on the test corridor.

The data reduction effort consists primarily of tabulating and cataloging the collected information. The major areas of analysis to be performed as part of this task consist of the development of balanced flow diagrams for the limited access facilities, and the development of the hourly volume variations for a typical weekday.

The basic procedures for developing the balanced network diagrams is discussed in the Handbook. It entails using the traffic volume data for all links and ramps on the freeway. The various data sources are converted to a common base year, a typical day, and a representative peak hour. Factors for this conversion are developed primarily from master station counts. The numerical balancing is the final step, wherein small adjustments are judiciously made to provide for "conservation of vehicles".

The process was applied to each limited access facility in the test corridor. A sample result for a portion of I-10 is shown in Figure 5.



NOTE: THIS FIGURE APPEARS AS FIGURE 5 IN THE HANDBOOK.

Figure 4. Data and Methodology Flow Chart

Table 8. Data Types And Sources for the Test Corridor

Type	Source
<p>1. Physical Inventory</p> <p>Roadway Geometrics</p> <p>Distance Between Intersections</p> <p>Lane Use</p> <p>Number of Lanes</p> <p>Roadside Land Use</p> <p>Arterial Lane Widths</p> <p>Posted Speed Limits</p> <p>Motorist Aid Telephones</p>	<p>USGS maps (scale 1:24,000). L.A. County Official Street maps (scale 1:1000). Miscellaneous Oil Company and AAA maps. Cal. DOT Highway Characteristics Reference Table for State Hwys. USGS maps. Field investigation at critical intersections. Field survey. Cal DOT L.A. District Trans. Planning Office. Field measurement at critical intersections. Recorded during field surveys. Discussions with Cal DOT Fwy Ops office and CHP.</p>
<p>2. Problem Identification</p> <p>Critical Intersections</p> <p>Critical Freeway Segments</p>	<p>Discussions with Cal DOT Traffic Signal Office, L.A. District, and L.A. County Traffic Engineers. Discussions with Cal DOT Freeway Ops Office.</p>
<p>3. Volume</p> <p>AADT</p> <p>Peak and Off-Peak Vols.</p> <p>Ramp Volumes</p> <p>Turning Movements</p> <p>Hourly Volumes</p> <p>Weekend and Recreational Vol.</p> <p>Adjustment Factors</p>	<p>Book "1976 Traffic Volumes on the Calif. State Hwy System," L.A. County master station data, '76/'77 (computer printout). Above master station data. Cal DOT Arterial Hwys (computer printout). L.A. County Arterial Hwys (computer printout). L.A. County machine counts at some locations (computer printout). Cal DOT District Office. L.A. County, typical intersections (computer printout). Cal DOT Arterial Hwys (computer printout). Discussions with Cal DOT L.A. District Office. L.A. County Arterial Hwys (some computer printout). Available from Cal DOT, Sacramento. Derived from other volume data.</p>
<p>4. Travel Time, Speed, and Delay</p> <p>Travel Time</p>	<p>Recorded in field on Arterial Network. Cal DOT L.A. District office, speed/time-of-day contours for fwys (tachograph runs), derived.</p>

Table 8. Data Types And Sources for the Test Corridor (Continued)

Type	Source
Speed and Delay	Above tachograph runs.
5. Intersection Control Typical Actuated Splits  Special Timing Policy  Phase Sequence Policy Interconnected Systems	Discussions with L. A. County Traffic Engineers, Cal DOT L. A. District Office for critical intersections. Discussions with Cal DOT L. A. District Office and L. A. County Traffic Engineers. Same as above. L. A. County Traffic Systems Office. Cal DOT L. A. District Office.
6. Origin-Destination Ramp to Ramp Zone to Zone	Not available. Cal DOT L. A. District Trans. Planning Office (data not current).
7, 8 Accident and Incident Rates on Freeways  High Accident Locations  Incident Rates on Freeways Patrol and Tow Policy	Cal DOT, 1 year and 3 year records by .01 milepost on State arterials and fwys (computer printout). Cal DOT, actual and expected rates (computer printout). Same as above. Discussions with L. A. County. Not available. Discussions with CHP.
9. Planned Highway Construction	Discussions with Cal DOT L. A. District Transportation Planning Office.
10. Planned Land Development	Same as above.

The typical hourly volume variations also involve conversion of data to a common base. Master station data and other available machine counts are used for this purpose. Figure 6 illustrates a sample result for the test corridor.

Reference to other aspects of the assembled data base will be made in subsequent sections of the report where the data are used.

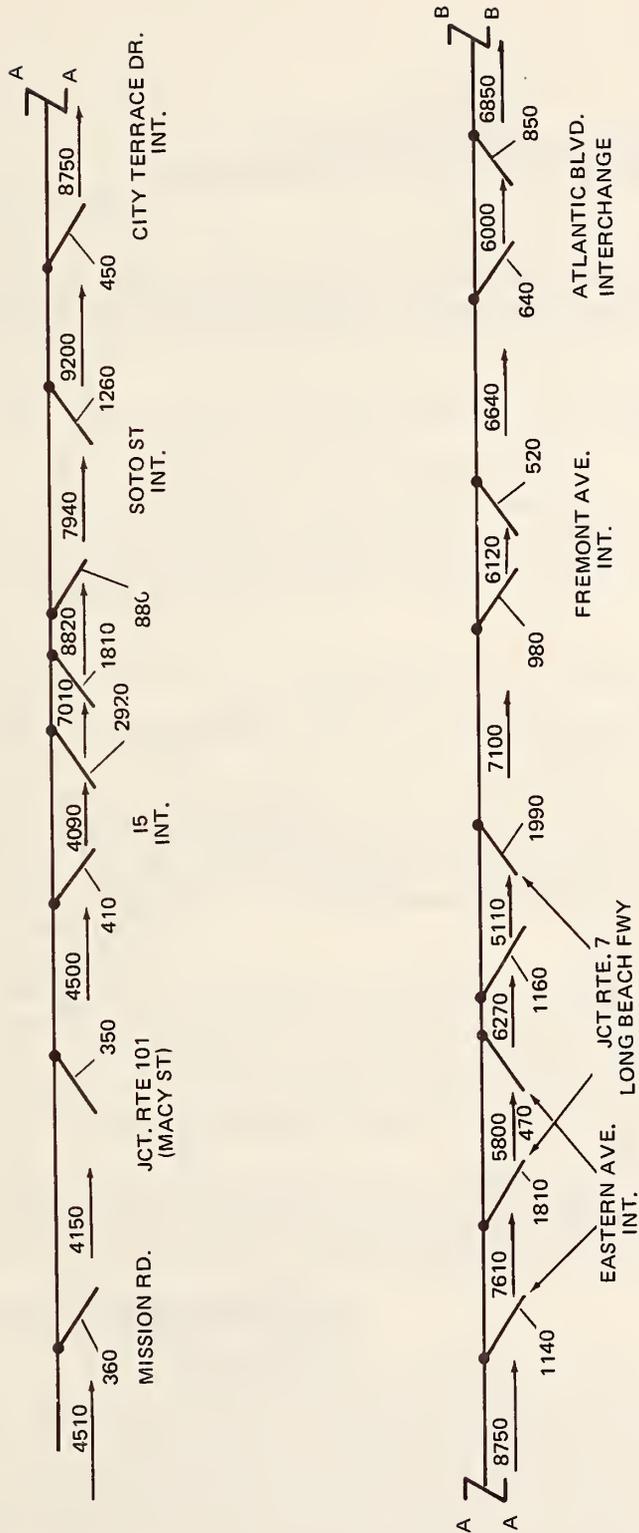


Figure 5. Balanced Freeway Volumes

I-10 CONTROL STATION 705, MILE POST 42.664

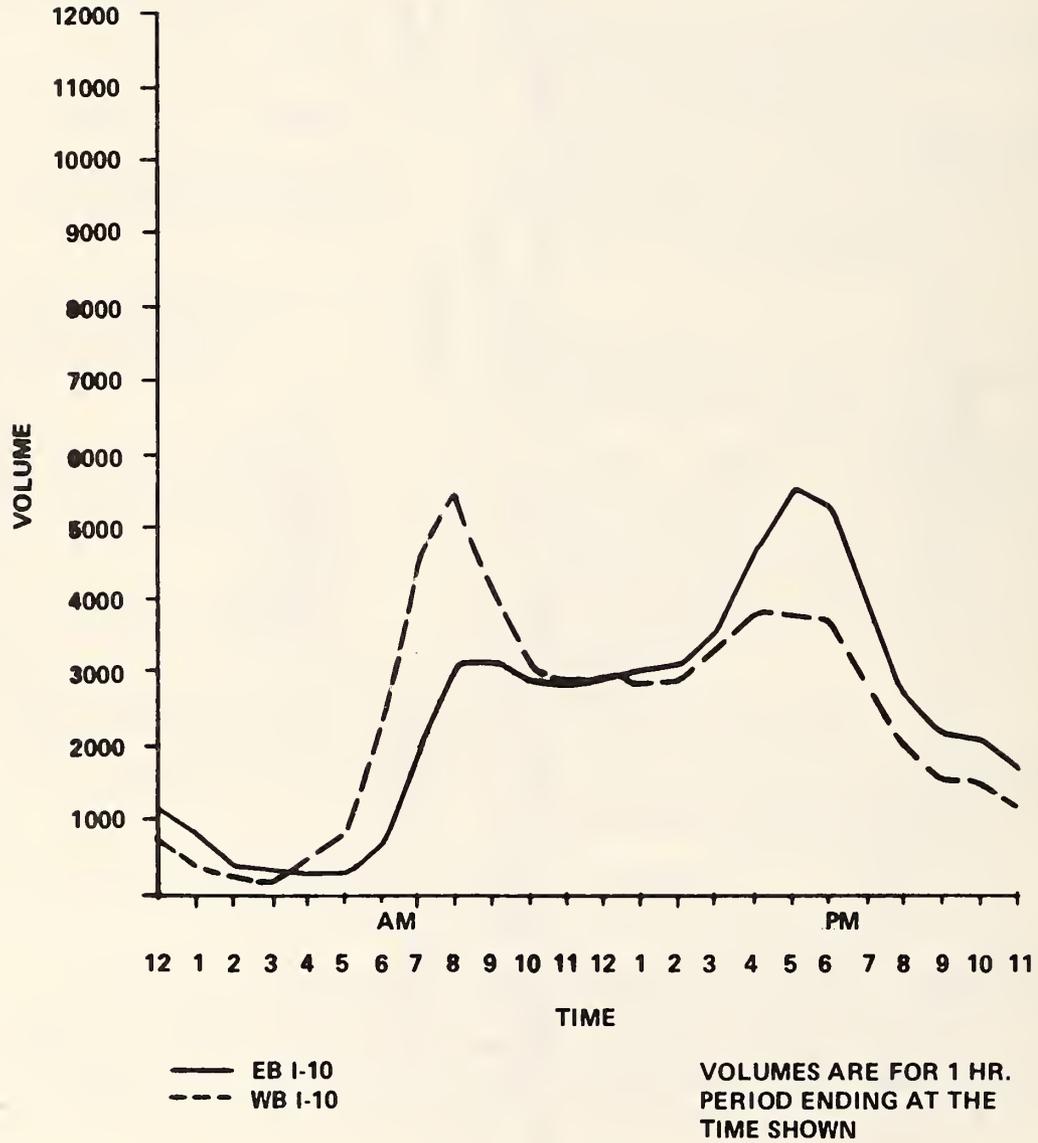


Figure 6. Typical Hourly Volume Distribution

## SECTION 7

### SUPPLEMENTAL ANALYSES

#### 7.1 INTRODUCTION

In this section, the series of supplemental analyses defined in the Handbook are performed for the test corridor. These analyses serve to develop additional information required for subsequent tasks in the methodology.

The major outputs of this task are the following:

- Control probability model coefficients
- Accident/incident rates for the main limited access roadways
- Capacity analysis for the alternate routes
- Origin-destination pattern (freeway ramp-to-ramp)
- Median trip length

Each of the above are discussed in the remaining paragraphs of this section.

#### 7.2 CONTROL PROBABILITY MODEL COEFFICIENTS

The purpose of this step in the methodology is to obtain a measure of the variability of traffic on the freeways for subsequent use in the benefit determination task. The measure is in the form of the mean and standard deviation of traffic volumes during the peak periods. These represent the coefficients of the control probability model.

The procedure consists of tabulating at least four or five weeks of hourly volume count data (usually from permanent count stations). The counts are then converted to a common base by applying daily and monthly factors. Finally, the means and standard deviations for each data set are calculated using the standard equations for these parameters.

The results of applying the procedure for the test corridor are presented in Table 9 for four data sets (two hours in the peak period, two different locations). It is seen that the variability is approximately 125 vehicles per hour per lane.

#### 7.3 ACCIDENT/INCIDENT RATES

The methodology makes use of accident (and incident) rates in the dimensional form of accidents per lane-mile per hour (one lane-mile = 1.61 lane-kilometers). Thus the objective here is to transform the available data into these units. Also, representative or average rates may be used over major freeway sections experiencing reasonably similar ADT's. In general, the test corridor has high ADT's in the western half, and lower ADT's in the eastern half, with I-605

Table 9. Traffic Volume Data

CTL. STAT #721		4 LANES						
4-5 PM PEAK		DAILY FACTOR	1.05 M	1.02 T	1.01 W	.99 TH	1.01 FR	
<u>MONTHLY FACTOR</u>								
1.0	3/14/77	7080 (7434)	7510 (7660)	7320 (7302)	7540 (7465)	7310 (6798)		RAW (FACTORED)
1.01	11/1/76	7180 (7614)	7150 (7366)	7340 (7488)	7000 (6999)	6460 (6068)		
1.01	11/15/76	7380 (7826)	6950 (7160)	6770 (6906)	6450 (6449)	7270 (6829)		
1.04	4/18/77	7550 (8245)	7100 (7532)	7300 (7668)	6930 (7135)	6840 (6616)		
1.00	6/6/77	6810 (7150)	7070 (7211)	7500 (7575)	7530 (7455)	6140 (6268)		
MEAN ( $\bar{Q}$ ) AND STD DEV ( $\sigma_{\bar{Q}}$ ):			$\bar{Q} = 7209$ VPH	$\sigma_{\bar{Q}} = 505$ VPH				
PER LANE VALUES OF ABOVE:			$\bar{Q}_{LN} = 1802$ VPHPL	$\sigma_{\bar{Q}_{LN}} = 126$ VPHPL				
5-6 PM PEAK			M	T	W	TH	FR	
1.0	3/14/77	6580 (6909)	7120 (7262)	6810 (6878)	7000 (6930)	6490 (6036)		
1.01	11/1/76	6670 (7074)	6670 (6871)	6650 (6784)	6510 (6509)	7130 (6697)		
1.01	11/15/76	6960 (7381)	6590 (6789)	6800 (6937)	5670 (5669)	6510 (6615)		
1.04	4/18/77	6850 (7480)	7170 (7606)	6840 (7185)	7130 (7341)	6330 (6122)		
1.00	6/6/77	6970 (7319)	7470 (7619)	6850 (6919)	7240 (7168)	7120 (6622)		
			$\bar{Q} = 6889$	$\sigma_{\bar{Q}} = 502$				
			$\bar{Q}_{LN} = 1722$	$\sigma_{\bar{Q}_{LN}} = 126$				
CTL. STAT #752		6 LANES						
4-5 PM PEAK		DAILY FACTOR	1.05 M	1.01 T	1.01 W	1.00 TH	.96 FR	
<u>MONTHLY FACTOR</u>								
1.02	10/11/76			9020 (9292)	8760 (9024)	8960 (9139)	8460 (8284)	RAW (FACTORED)
1.05	3/14/77	9730 (10727)	9730 (10319)	8510 (9025)	8520 (8946)	9010 (9082)		
.90	5/16/77	9140 (8637)	9390 (8535)	9450 (8590)	8990 (8091)	8670 (7491)		
.90	5/23/77	8500 (8032)	9330 (8481)	9500 (8635)	9360 (8426)	9240 (7984)		
.98	6/6/77	9110 (9374)	9540 (9443)	8970 (8878)	9030 (8849)	8920 (8392)		
			$\bar{Q} = 8820$	$\sigma_{\bar{Q}} = 711$				
			$\bar{Q}_{LN} = 1470$	$\sigma_{\bar{Q}_{LN}} = 119$				
			M	T	W	TH	FR	
1.02	10/11/76			8200 (8448)	8160 (8460)	8120 (8282)	7630 (7471)	
1.05	3/14/77	9240 (10187)	8990 (9534)	7590 (8049)	7520 (7896)	7290 (7348)		
.90	5/16/77	8890 (8401)	8870 (8063)	8670 (7881)	8910 (8019)	7990 (6903)		
.90	5/23/77	9040 (8543)	8890 (*8081)	8900 (8090)	8690 (7821)	7770 (6713)		
.98	6/6/77	8560 (8808)	8700 (8611)	8620 (8532)	8670 (8497)	8450 (7949)		
			$\bar{Q} = 8189$	$\sigma_{\bar{Q}} = 733$				
			$\bar{Q}_{LN} = 1365$	$\sigma_{\bar{Q}_{LN}} = 122$				

serving as the dividing line. Therefore two sets of average rates are developed, one for each of these major segments.

As the first step in the process, the available accident data for each section of roadway are converted to units of accidents per 100 million vehicles miles of travel (per 161 million vehicle kilometers of travel). These are then averaged over each major segment. Finally, they are converted to the units required for the methodology.

Table 10 shows the basic data used and the results of the first conversion and averaging for I-10. It is noted that a three year data base was available, and this was used in the computation. The equation for calculating the accident rate was as follows:

$$\text{Accident Rate} = \frac{\text{Total Number of Accidents (3 yrs.)}}{3 \times \text{Length of Section} \times \text{ADT} \times 365 \text{ days/yr}} \times 10^8$$

Table 11 shows the similar results for the Cal 60 freeway.

For the case of I-210, the data base was insufficient to follow the same process (partly because sections of the roadway were only recently constructed). Therefore, an approximating procedure was used instead. This procedure consisted of plotting the accident rate data from the I-10 and Cal 60 roadway sections on an ADT per lane basis (see Figure 7), and then estimating the I-605 accident rate based on its ADT per lane. The following ADT and lane data for I-605 were used.

- Rt 7/134 to Rosemead Blvd.  
10 lanes, ADT = 99,000, ADT/lane = 9,900
- Rosemead to I-605  
8 lanes, ADT = 81,000, ADT/lane = 10,125
- I-605 to Rt 30  
8 lanes, ADT = 73,000, ADT/lane = 9,125

With the per lane ADT ranging roughly between 9,000 and 10,000, the accident rate was estimated to be approximately  $45/10^8$  VMT from the figure. This value was considered as the average rate over the total length of I-210.

The final conversion of the accident rates to the desired units mentioned earlier is summarized in Table 12. The conversion is accomplished via the following equation:

$$\text{Acc/lane-mi/hr} = \frac{\text{Acc}/10^8 \text{ VMT} \times \text{Hourly Volume}}{\text{number of lanes}} \quad (1 \text{ lane-mi} = 1.61 \text{ lane-km})$$

The hourly volumes (two-way) for each period were obtained from the typical weekday volume distribution curves prepared earlier.

Table 10. Accident Statistics for I-10

Milepost	Location	Section Length (Mi.)	Total Number Of Accidents (1/74-12/76)	ADT	Accident Rate Per 10 <sup>8</sup> VMT	Number of Lanes
18.4	Jct. Rt 101/I-5	.65	126	159,000	111.34	12
19.05	Soto St.	2.33	331	145,000	89.47	12
21.38	Jct. Rt. 7	1.95	412	145,000	133.07	8
23.33	Atlantic Blvd.	3.53	642	142,000	116.97	8
26.86	Rosemead Blvd.	2.69	348	139,000	85.0	8
29.55	Valley-Peck	1.03	118	127,000	82.38	8
30.58	Garvey Ave.	.57	167	142,000	188.43	8
31.15	Jct. I-605	5.33	570	115,000	84.93	8
36.48	Azusa Ave.	2.03	61	99,000	27.72	8
38.51	Grand Ave.	3.93	168	85,000	45.93	10
42.44	Jct. Rt. 57/I-210	12.75	2144	142,000	108.15	-
West Segment		11.29	799	102,000	63.36	-
East Segment						

(Note: 1 mile = 1.61 Km, rate per 10<sup>8</sup> VMT = rate per 1.61x10<sup>8</sup> VKmT)

Table 11. Accident Statistics for Cal 60

Milepost	Location	Section Length (Mi.)	Total Number Of Accidents (1/74-12/76)	ADT	Accident Rate Per 10 <sup>8</sup> VMT	Number of Lanes
0	Jct I-10/Rt 101	3.27	483	137,000	98.5	8
3.27	Jct. Rt. 7	1.16	185	169,000	86.2	10
4.43	Atlantic Blvd.	5.08	673	152,000	79.6	8
9.51	Rosemead Blvd.	1.50	173	152,000	69.3	10
11.01	Peck Rd.	0.70	97	146,000	86.7	8
11.71	Jct. I-605	4.22	419	132,000	68.7	8
15.93	Hacienda/Glendorra	2.04	128	108,000	53.1	8
17.97	Azusa Ave.	5.59	264	97,000	44.5	8
23.56	Jct. Rt. 57S	1.90	108	109,000	47.6	12
25.46	Jct. Rt. 57N	11.71	1611	149,000	84.3	-
West Segment		13.75	919	111,000	55.0	-
East Segment						

(Note: 1 mile = 1.61 Km, rate per 10<sup>8</sup>VMT = rate per 1.61x10<sup>8</sup>VKmT)

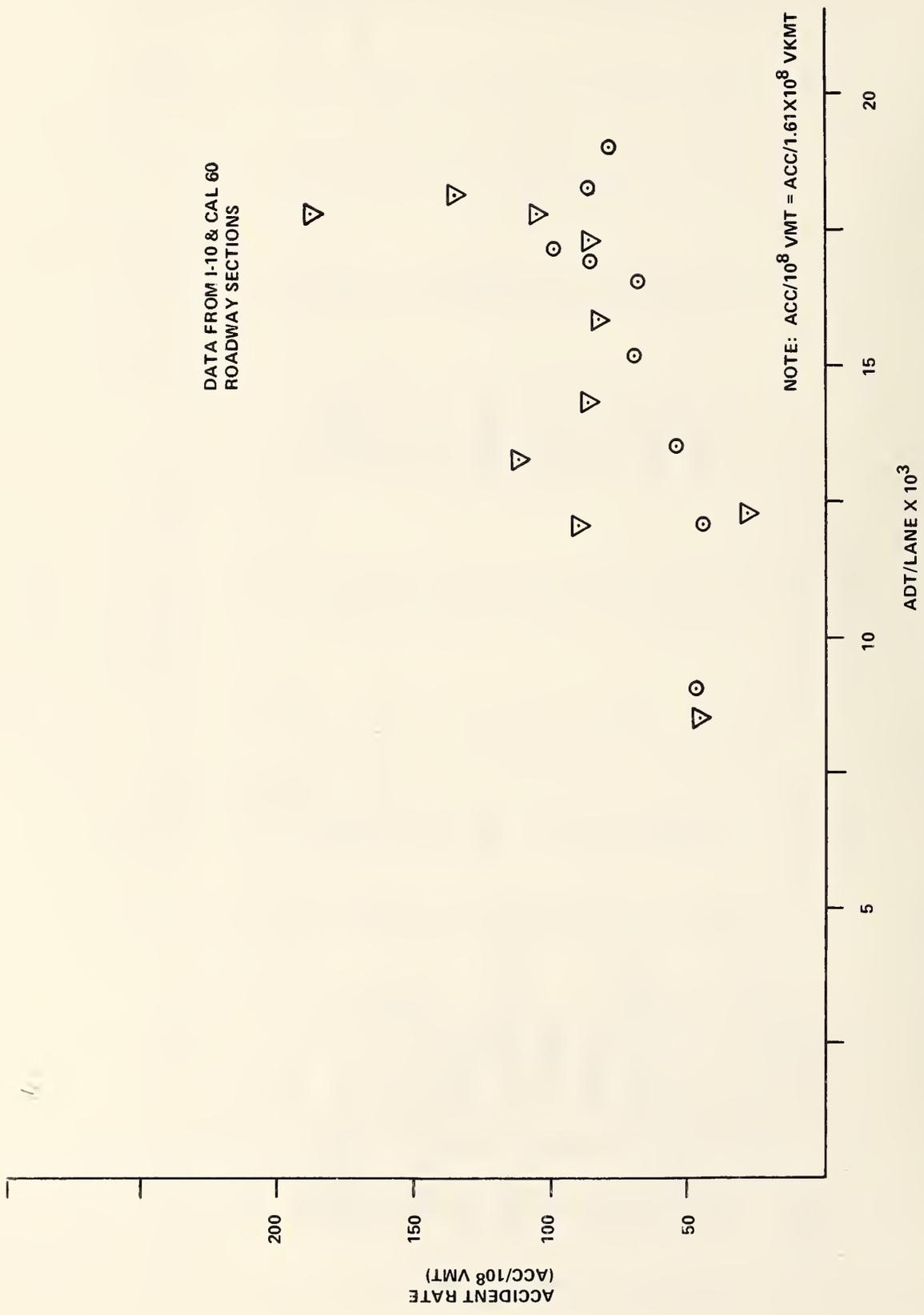


Figure 7. Accident Rate vs. Per Lane ADT

Table 12. Accident Rates (Converted Units)

Location	Hourly Period	2-Way Hourly Vol.	Acc/Lane-Mi/Hr
A. I-10, West of I-605 (108.15 Acc/10 <sup>8</sup> VMT, 8 lanes, ADT = 142,000, length = 12.75 mi.)	Peak	11,000	.00149
	Midday	7,000	.00095
B. I-10, East of I-605 (63.4 Acc/10 <sup>8</sup> VMT, 8 lanes, ADT = 102,000, length = 11.29 mi.)	Peak	9,500	.00075
	Midday	6,000	.000475
C. Cal 60, West of I-605 (84.3 Acc/10 <sup>8</sup> VMT, 8 lanes, ADT = 149,000, length = 11.71 mi.)	Peak	11,000	.00116
	Midday	7,000	.00074
D. Cal 60, East of I-605, (55.0 Acc/10 <sup>8</sup> VMT, 8 lanes, ADT = 111,000, length = 13.75 mi.)	Peak	9,000	.00619
	Midday	5,000	.000344
E. I-210 West of I-605, (45 Acc/10 <sup>8</sup> VMT, 8 lanes, ADT = 88,000, length = 11.45 mi.)	Peak	11,500	.00065
	Midday	5,000	.00028
F. I-210, East of I-605, (45 Acc/10 <sup>8</sup> VMT, 8 lanes, ADT = 73,000, length = 8 mi.)	Peak	9,250	.00052
	Midday	3,250	.00018

NOTE: 1 mile = 1.61 Km  
 1 lane-mile = 1.61 lane-Km  
 1 acc/ln-mi/hr = .62 acc/ln-Km/hr

Data on lane blocking incidents (other than accidents) were not available for the test corridor. Thus, the Handbook alternative was used. This alternative, which is based on two previous incident studies, states that the lane blocking rate due to incidents is approximately equal to the accident rate. The accident rate values contained in Table 12 are therefore assumed to be applicable to incidents as well.

#### 7.4 ALTERNATE ROUTE CAPACITY ANALYSIS

The capacity of an alternate route is dictated primarily by the capacity of the signalized intersections along the route. Standard traffic engineering procedures are used for the calculation, based primarily on inputs of signal timing and number of lanes. The ability of the route to handle additional traffic (available capacity) is determined by subtracting the present demand from the existing capacity.

In IMIS, the signals along alternate routes are placed under computer control, and thus capacity can be increased when required for diversion purposes. The available capacity likewise increases under these conditions. Nevertheless, the capacities calculated under the present timing policy serve to provide a measure of the relative utility of the route for diversion, and are therefore used in the route evaluation.

The analysis has been performed for the candidate routes in the test corridor. The results are summarized in Table 13.

#### 7.5 ORIGIN-DESTINATION PATTERN

Origin-destination data (freeway ramp to ramp) were not available for the test corridor. Therefore, the alternative cited in the Handbook, the origin-destination model, was used instead.

I-10, the central corridor freeway, was taken as a representative case. The balanced freeway network developed earlier provided the necessary input, and the calculations were performed following the Handbook procedures. Table 14 provides the listing of each entrance and exit ramp and the assigned identification number. (The "distance from start" column is for later use in the trip length determination.) A portion of the results of the calculations are presented for illustration in Figure 8. The form of the results is such that the following may be determined by inspection:

- The composition of each exit ramp volume, i. e., the number of exiting vehicles that had origins at each of the upstream entrance ramps (lower set of tabulations in the figure)
- The origins (entrance ramps) of the mainline volume in any link (upper tabulations in the figure). These values also indicate at any point, the volume remaining on the mainline which originated at any upstream entrance ramp.

Table 13. Alternate Route Capacity Analysis

Route & Location	No. of Lanes			Thru Split	Thru Capacity-VPH			Thru Vol. PM peak VPH	Available Capacity* PM Peak - VPH		
	Left Turn	Thru	Right Turn		C	D	E		C	D	E
Colorado Blvd. & Foothill Blvd. Eastbound from Cal 134 to Cal 30											
Lake	1	2		.45	1080	1220	1350	470	610	750	880
Huntington		2		.28	670	760	840	550	120	210	290
Azusa	1	2		.55	1320	1490	1650	500	820	990	1150
Damien		2		.74	1780	2000	2220	1350	430	650	870
Colorado Blvd. & Foothill Blvd. Westbound from Cal 30 to Cal 134											
Damien	1	2		.84	2020	2270	2520	630	1390	1640	1890
Azusa	1	2		.29	700	780	870	280	420	500	590
Huntington	1	2		.62	1490	1670	1860	360	1130	1310	1500
Lake	1	2		.45	1080	1220	1350	450	630	770	900
Mission Rd. & Huntington Dr. Westbound from Colorado Blvd. to US 101											
Colorado	1	2		.62	1490	1670	1860	740	750	930	1120
Main	1	3		.57	2050	2310	2570	630	1420	1680	1940
Soto	2	1		No Sig	1200	1350	1500	700	500	650	800
Valley		2		.3	720	810	900	800	(80)	10	100
Soto St. Southbound from Huntington Dr. to I-10											
Huntington		2	1	No Sig	2400	2700	3000	700	1700	2000	2300
Marengo	1	2	1	.75	1800	2025	2250	500	1300	1525	1750
Main St., Las Tunas Dr., Live Oak Aves. & Arrow Hwy Westbound from I-210 to Huntington Drive											
Azusa	1	2	1	.16	380	430	480	400	(20)	30	80
Huntington	2		1	.33	790	890	990	590	200	300	400
Valley Blvd. Eastbound from Mission Rd. to Cal 57											
Mission			1	No Sig	1200	1350	1500	900	300	450	600
Cal 7		3		.43	1550	1740	1940	1200	350	540	740
Rosemead	1	2		.33	790	890	990	1000	(210)	(110)	(10)
Garvey	1	2		.48	1150	1300	1440	1400	(250)	(100)	40
I-605	1	2		.64	1540	1730	1920	1100	440	630	820
Hacienda	1	2	1	.25	600	680	750	700	(100)	(20)	50
Azusa	1	2		.56	1340	1510	1680	800	540	710	880
Temple	1	2	1	.59	1410	1590	1770	330	1080	1250	1440
Valley Blvd. Westbound from Cal 57 to Mission Rd.											
Temple	1	2	1	.59	1410	1590	1770	250	1160	1340	1520
Azusa		2	1	.56	1340	1510	1680	550	790	960	1130
Hacienda	1	2	1	.16	380	430	480	420	(40)	10	60
I-605		2		.36	860	970	1080	850	10	120	230
Garvey	1	2		.48	1150	1300	1440	1400	(250)	(100)	40
Rosemead	1	2		.33	790	890	990	600	190	290	390
Cal 7	2	2		.43	1030	1160	1290	900	130	260	390
Mission	1	2		.30	720	810	900	700	20	110	200
Ramona Blvd. & Garvey Ave. Eastbound from I-10 to I-10											
Eastern	1	2	1	.50	1200	1350	1500	1100	100	250	400
Atlantic	1	2	1	.45	1080	1210	1350	1000	80	210	350
Rosemead	1	2	1	.32	770	860	960	900	(130)	(40)	60
Valley		2	1	.26	620	700	780	700	(80)	0	80
Garvey Ave. Westbound from I-10 to Atlantic Ave.											
Valley		2	1	.26	620	700	780	550	70	150	230
Rosemead	1	2	1	.18	430	490	540	500	(70)	(10)	40
Atlantic	1	2	1	.45	1080	1220	1350	500	580	720	850
Atlantic Ave. Northbound from Garvey Ave. to I-10											
Garvey	1	2	1	.45	1080	1220	1350	1000	80	220	350
Rosemead Blvd. Northbound from Cal 60 to Valley Blvd.											
Garvey	1	2	1	.35	840	950	1050	1000	(160)	(50)	50
Valley	1	2		.55	1320	1490	1650	1250	(70)	240	400
Rosemead Blvd. Southbound from Valley Blvd. to Cal 60											
Valley	1	2		.55	1320	1490	1650	850	470	640	800
Garvey	1	2	1	.38	910	1030	1140	1100	(190)	(70)	40
Hacienda Blvd. Northbound from Cal 60 to Valley Blvd.											
Valley	1	2	1	.44	1060	1190	1320	950	110	240	370
Hacienda Blvd. Southbound from Valley Blvd. to Cal 60											
Valley	1	2	1	.33	790	890	990	950	(160)	(60)	40
Azusa Ave. Northbound from Cal 60 to Valley Blvd.											
Gals	1	3		.43	1550	1740	1940	1200	350	540	740
Azusa Ave. Southbound from Valley Blvd. to Cal 60											
Gals	1	3		.43	1550	1740	1940	1100	450	640	840
Azusa Ave. Northbound from I-10 to Foothill Blvd.											
I-10	1	3		.50	1800	2030	2250	1200	600	830	1050
Arrow H	1	2	1	.29	700	780	870	750	(50)	30	120
Foothill	1	2	1	.31	740	840	930	530	210	310	400
Azusa Ave. Southbound from Foothill Blvd. to I-10											
Foothill	1	2	1	.31	740	840	930	600	140	240	330
Arrow	1	2	1	.27	650	730	810	700	(50)	30	110
I-10		3		.50	1800	2030	2250	1050	750	980	1200

\*Numbers in parentheses indicate a capacity deficiency, i.e., demand volume exceeds capacity.

Table 14. Ramp Listing for O-D Model (I-10 Facility)

Entrance Ramps		Exit Ramps		Distance From	
Name	ID No.	Name	ID No.	Start*	
I-10 (Mainline Input)	1			0	
Jct. Rt. 101 (Macy St.)	3	Jct. Rt 101 (Macy St.)	2	0.5	0.1
I-5 Int	5	I-5 Int	4	1.2	1.0
I-5 Int	7			1.3	
Soto St. Int	9	Soto St. Int	8	1.9	1.4
		City Terrace Dr. Int	10		2.8
		Eastern Ave. Int	12		3.2
		Jct Rte 7	14		3.4
Eastern Ave Int	15			3.7	
Jct. Rte 7	17	Jct Rte 7	16	4.3	3.8
Fremont Ave. Int	19	Fremont Ave. Int	18	5.1	5.0
Atlantic Blvd Int	21	Atlantic Blvd Int	20	6.2	5.9
Garfield Ave Int	23	Garfield Ave Int	22	6.8	6.6
New Ave Int	25	New Ave Int	24	7.7	7.5
Delmar Ave Int	27	Delmar Ave Int	26	8.2	7.9
San Gabriel Blvd Int	29	San Gabriel Blvd Int	28	8.7	8.5
Walnut Grove Int	31	Walnut Grove Int	30	9.1	9.0
Rosemead Blvd Int	33	Rosemead Blvd Int	32	9.5	9.5
Baldwin Ave Int	35	Baldwin Ave Int	34	9.9	10.7
Santa Anita Ave Int	37	Santa Anita Ave Int	36	10.9	11.3
		Peck Rd/Valley Ave Int	38	11.6	11.9
		Peck Rd/Valley Ave Int	40		12.2
Peck Rd/Valley Ave Int	41			12.3	
Peck Rd/Valley Ave Int	43			12.8	
Garvey Ave. Int	45			13.5	
		Jct I-605	46		13.8
Jct I-605	49	Jct I-605	48	14.2	14.0
		Bess & Frazier Int	50		14.4
Baldwin Park Blvd	53	Baldwin Park Blvd	52	15.3	15.0
		Francisquito Ave Int	54		15.5
Puente Ave Int	57	Puente Ave Int	56	16.4	16.3
Orange & Pacific Int	59	Orange & Pacific Int	58	17.3	17.2
Glendora & Vincent Int	61	Glendora & Vincent Int	60	18.2	18.1
Glendora & Vincent Int	63	Glendora & Vincent Int	62	18.4	18.3
Azuza Ave/Rte 39 Int	65	Azuza Ave Rte 39 Int	64	19.5	19.4
Citrus Ave Int	67	Citrus Ave Int	66	20.5	20.4
Barranca St Int	69	Barranca St Int	68	20.9	20.7
Grand Ave Int	71	Grand Ave Int	70	21.3	21.2
Holt Ave Int	73	Holt Ave Int	72	22.5	21.7
Via Verde Int	75	Via Verde Int	74	23.4	23.1
		I-10 (Mainline Out)	76		24.6

\* All distances are in miles  
 Note: 1 mile = 1.61 kilometers

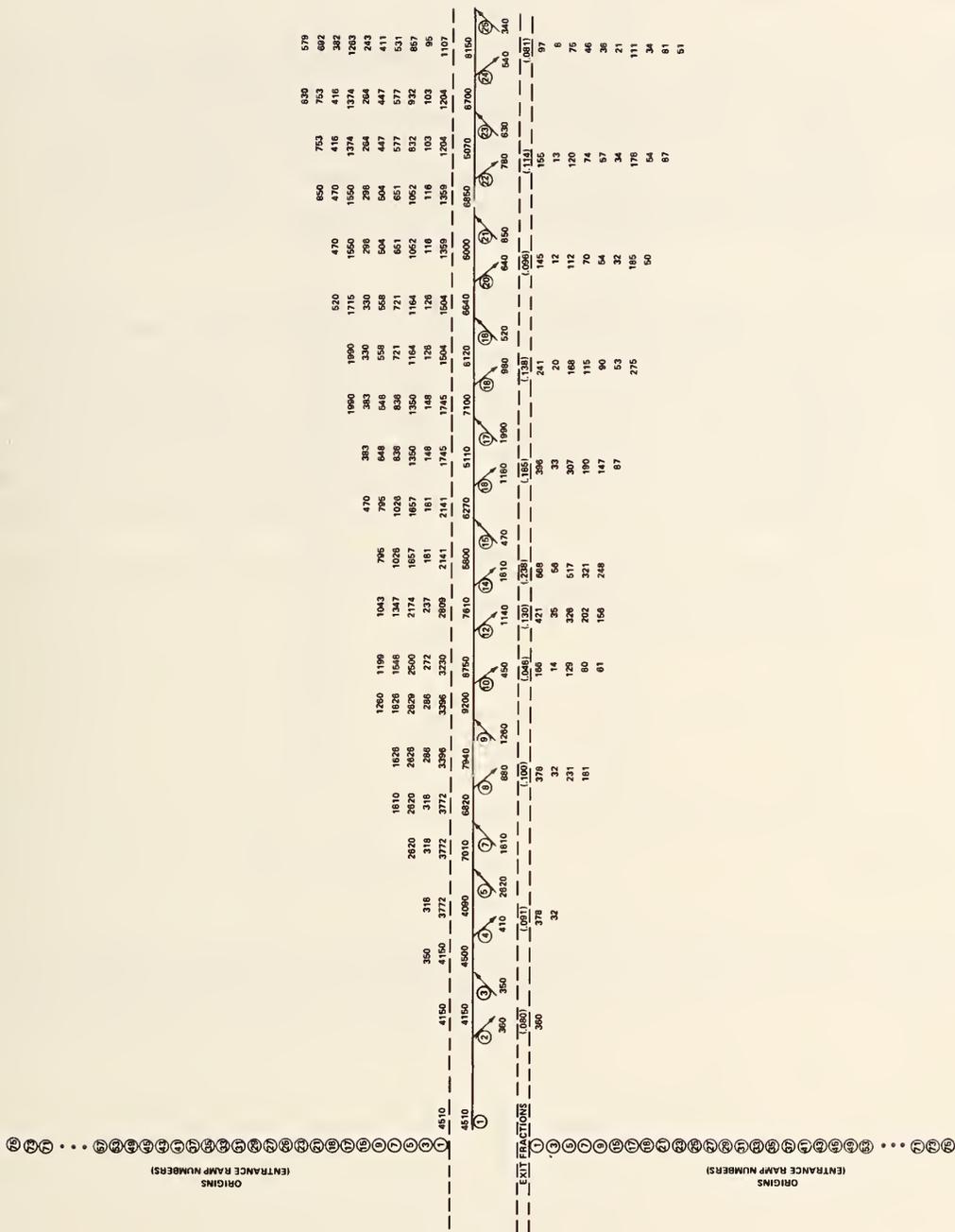


Figure 8. Origin-Destination Computation (I-10 Facility)

The above results are used in the trip length determination, which follows in the next paragraph.

## 7.6 MEDIAN TRIP LENGTH

In this step, the median trip lengths (i. e. lengths travelled by 50 percent of the vehicles) are calculated at several points (exit ramps) along the freeway. The results are then averaged to develop a composite number for the freeway. The only data required, in addition to the origin destination computation results, is the specification of distances between the corresponding ramps. (Distances of each ramp from the starting point have already been entered on the O-D ramp list. A simple subtraction provides the ramp to ramp values).

Using the figure containing the origin-destination results, the trip length determination procedure is fairly straightforward. Corresponding to each origin (entrance ramp), shown as the upper left "scale" in the figure, read horizontally to the right until its volume has dropped to approximately 1/2 of its initial value. Note the exit ramp at which this occurs, and calculate the distance between that entrance and exit ramp. The latter then represents the median trip length for that origin in the corridor. The process is continued for each entrance ramp until the 50 percent points fall beyond the last exit ramp. The results for each ramp are then averaged.

The steps have been accomplished for the representative case in the test corridor, and the results are indicated in Table 15.

Table 15. Median Trip Lengths (MTL) on I-10

Ent. Ramp No.	Vol.	Exit No. For MTL	MTL (Miles)
1	4510	14	3.4
3	350	16	3.3
5	2920	16	2.6
7	1810	16	2.5
9	1260	18	3.1
15*	470	28	4.8
17	1990	32	5.2
19	520	34	5.6
21	850	34	4.5
23	630	36	4.5
25	340	38	4.2
27	340	38	3.7
29	400	46	5.1
31	370	46	4.7
33	1260	48	4.1
35	1070	50	3.5
37	650	52	3.4
41	350	56	4.0
43	210	56	3.5
45	840	56	2.8
49	2930	64	5.2
53	290	68	5.4
57	490	70	4.8
59	350	72	4.4
61	650	76	6.4

(Note: 1 Mile = 1.61 Kilometers)

Avg MTL = 4.2 Miles

\* For entrance ramps 15 through 61, values were derived from the remaining portion of the origin-destination worksheet not shown in Figure 8 (i.e., Figure 8 only shows the initial part of the worksheet).

## SECTION 8

### ALTERNATE ROUTE ANALYSIS

#### 8.1 INTRODUCTION

In this section, the candidate alternate routes are ranked relative to their associated primary routes, following the procedures contained in the Handbook.\* The necessary input data are available from the previous sections.

#### 8.2 THE PRIMARY AND ALTERNATE ROUTES

There are three primary routes in the corridor, i. e., I-10, Cal 60, and I-210. Each of these is listed below along with their associated alternate routes. The baseline corridor map developed in Section 5 (Figure 3) is repeated here as Figure 9 for convenience of reference.

##### A. Primary Route I-10

Alternate routes considered are:

- Valley Blvd
- Garvey Ave. plus eastern part of Valley Blvd
- Mission/Huntington/Las Tunas/Live Oak/Arrow
- Mission/Huntington/I-210

It is noted that an exception is made for the last alternate route shown above, i. e., it includes a section of a primary route (I-210). As can be seen from the corridor map, this would be the logical choice over Foothill Blvd. for the eastern portion of the route.

##### B. Primary Route Cal. 60

Alternate routes considered are:

- Valley Blvd
- Garvey Ave. plus eastern part of Valley Blvd

-----  
\*Although primary routes can also serve as "alternates" for each other, they are not so ranked, since their designation as a primary route implies that they are not subject to elimination (except when a portion of the corridor as a whole is eliminated).

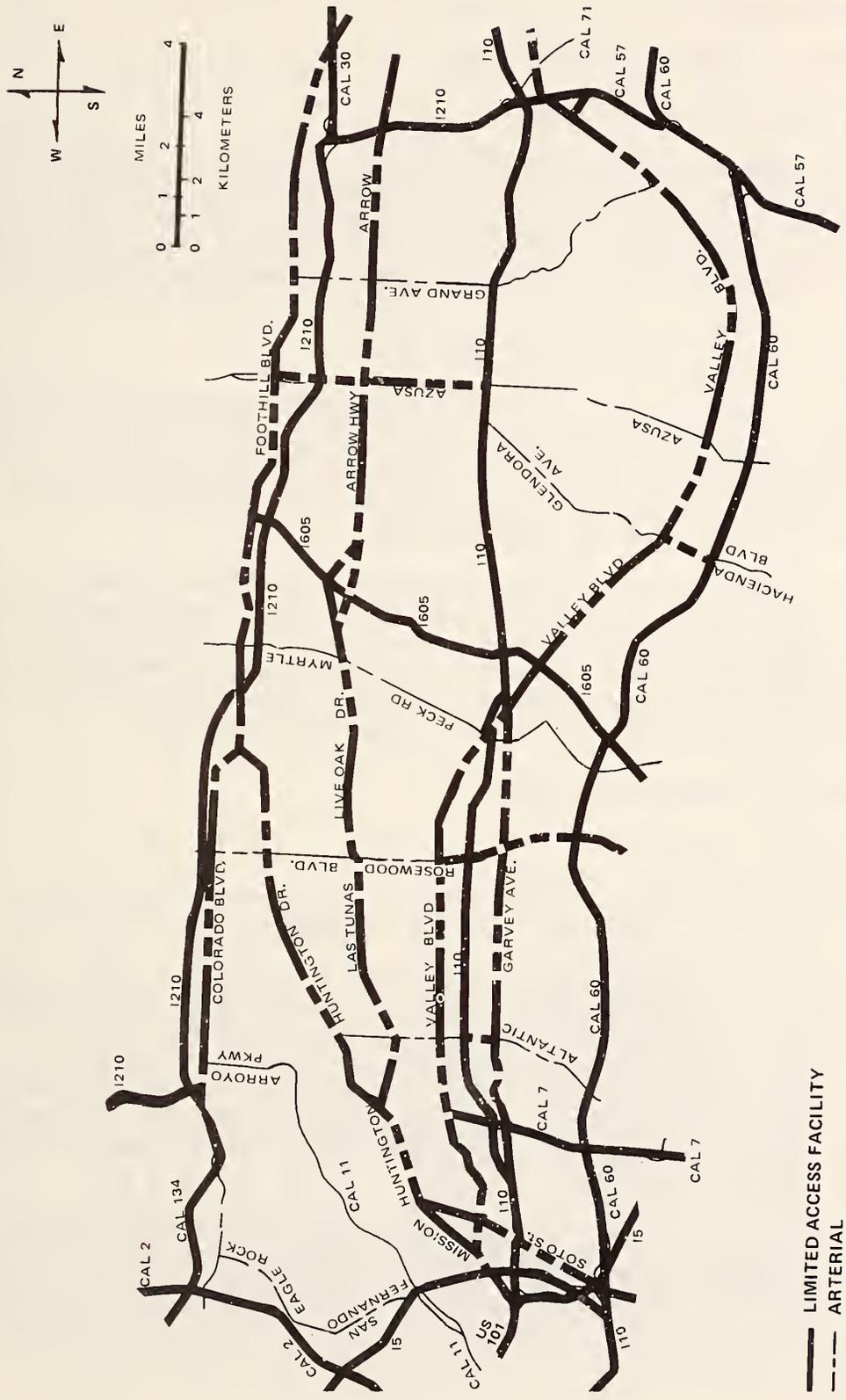


Figure 9. Baseline Corridor Map

## C. Primary Route I-210

Alternate routes considered are:

- Foothill/Colorado Blvd

With the exception of area in the vicinity of I-605, there are no significant congestion problems along I-210. Thus, in the absence of other alternate routes comparable to Foothill/Colorado, only the single alternate is included. For this type of situation, it is not necessary to rank the alternate, since it will not be compared to any other. As long as I-210 remains as a part of the corridor network, the alternate is retained with it.

### 8.3 RANKING OF ALTERNATE ROUTES

The Handbook provides a typical worksheet for use in ranking the alternate routes. The worksheet defines the procedure for calculating the values of the seven basic characteristics included in the ranking. It also provides typical "weighting" factors (which may be changed by the using agency), and "scale" values to convert the results to a common base.

In the following paragraphs, the ranking of the alternate routes is accomplished. Calculations of the basic characteristic values ("raw values") are discussed and the results are entered on a worksheet. The scale value for each raw value is determined from the worksheet. Multiplying the scale value by the weight (indicated on the worksheets) produces the score for each characteristic. Then, the sum of scores yields the overall score of the alternate route.

#### 8.3.1 Alternates for Primary Route I-10

##### A. Valley Blvd. (Table 16)

- Characteristic 1: Valley Blvd can bypass essentially the entire length of I-10. Its raw value is thus 100 percent for this characteristic.
- Characteristic 2: The average value of peak hour available capacity along the alternate route is obtained from the capacity analysis results (Section 7). This average value for the PM peak hour (Eastbound) is 570 vehicles per hour (vph). The capacity of the primary route is taken as 1800 vph per lane. Since the major portion of I-10 is 4 lanes, its capacity is taken as 7200 vph. The raw value for this characteristic is then  $(570/7200) \times 100 = 7.9$  percent (round off to 8 percent).
- Characteristic 3: This characteristic accounts for the distance penalty associated with using the alternate route. Based on scaled mileages, the raw value (expressed as a percent) is 87.

Table 16. Alternate Route Scoring (Primary Route: I-10, Alternate Route: Valley Blvd)

Alternate Characteristics	Raw		Scale	
	Value	Weight	Value	X Weight
1. Length of primary route bypassed in percent of primary route length	100	.05	100	5.0
2. Average peak hour available capacity of alternate* in percent of primary route capacity	8	.20	80	16.0
3. Length of primary route bypassed as percent of length of alternate (include length of connector routes)	87	.15	80	12.0
4. Peak hour primary route travel time as percent of alternate route travel time (include connector route travel time)	63	.20	60	12.0
5. Additional connectors. Average number of additional connectors per mile of primary route** (round off to nearest tenth)	0.2	.10	20	2.0
6. Land use. Percent of alternate route dedicated to non-residential use.	95	.10	100	10.0
7. Other factors. Grade from 0-100, Deduct for school zones, railroad grade crossings, high accident frequency and other qualitative factors.	70	.20	70	14.0

\*Use the average (rather than the minimum) of the individual intersection available capacities, to compensate for the fact that capacities are calculated without computerized signal control operations.

\*\*If the average available capacity of any connector is less than 50 percent of that of the alternate route, disregard that connector.

Total Score = 71.0

Characteristic	Raw Value	Scale Value
No. 2	≥ 10	100
	9	90
	8	80
	7	70
	6	60
	5	50
	4	40
	3	30
	2	20
	1	10
	0	0
No. 5	≥ 1.0	100
	0.9	90
	0.8	80
	0.7	70
	0.6	60
	0.5	50
	0.4	40
	0.3	30
	0.2	20
	0.1	10
	0	0
No. 1, 3, 4, 6, 7	95-100	100
	90-94	90
	80-89	80
	70-79	70
	60-69	60
	50-59	50
	40-49	40
	30-39	30
	20-29	20
	10-19	10
	0-10	0

- **Characteristic 4:** Using the travel time data collected during the study, the average travel times for primary route and alternate route are, respectively, 34.4 minutes and 54.5 minutes. The raw value is thus 63 (percent).
- **Characteristic 5:** There are 4 additional connectors between the primary route and the alternate route (Cal 7, Rosemead, the cross-over, and I-605). All have the required available capacity to be included. The primary route is approximately 24 miles (39 km) long. Thus, the raw value is  $4/24 = 0.17$ , which is rounded off to 0.2.
- **Characteristic 6:** This alternate route is mostly non-residential. Based on the field trip, the value is estimated to be about 95 percent.
- **Characteristic 7:** For these other factors, only limited information was available (high accident intersection data were not available). Therefore, qualitative judgment was used to assess route quality. On this basis, 30 points were deducted yielding a raw value of 70.

**Total Score:** After converting to scale values and weighting them, the sum of the scores for the individual characteristics produces a total score of 71 for this alternate route. (See Table 16.)

#### B. Other Alternate Routes for I-10

Following the above procedures, the other 3 alternate routes for I-10 were scored. The results are noted in paragraph C, below.

#### C. Discussion

The four alternate routes and their resulting scores are as follows:

Valley	71
Garvey/Valley	66.5
Mission/..../Arrow	48
Mission/Hunt/I-210	59

The first two of the above are the highest ranked. They are generally comparable, due in part to the common section (Valley Blvd in the eastern half). Overall, their characteristics are reasonably good. With each route being close to and on opposite sides of the western (most congested) portion of I-10, both provide good utility for diversion.

The low ranking of the third alternate stems mainly from two factors. The first is the lesser amount of available capacity during the peak hours. The

second is its low utility for diversion in the western portion (where most needed) due to divergence from and connectivity problems with I-10. This shortcoming was assessed under "other factors", where a large number of points were deducted.

The fourth alternate was also downgraded under "other factors" for reasons similar to the above. Its other characteristics were generally good, providing it with a better ranking than the third alternate.

The overall conclusion (related to configuring alternative designs) is that the first two alternate routes have the highest priority for retention. The third and fourth alternates are candidates for exclusion, the former having the lowest retention priority.

### 8.3.2 Alternates for Primary Route Cal 60

The two alternate routes considered for Cal 60, i. e., Valley and the Garvey/Valley combination have been scored and the results are presented below.

Valley	59.5
Garvey/Valley	67.0

Travel time and the "other factors" (better utility in the western portion) were the primary reasons for the higher scoring of the latter, and it ordinarily would have a higher retention priority than the former. These results, however, must be considered in conjunction with those for I-10, since the alternate routes are common for both. Actually, the south-west quadrant of the total corridor represents a small corridor in itself, with the two primary routes and two alternate routes comprising an integrated network. Because this is the most congested area in the total corridor, it would appear logical to retain this integrated network for maximum diversion potential. Thus, when the western portion of the corridor is considered, both alternate routes should be included.

### 8.3.3 Alternates for Primary Route I-210

As noted earlier, only one alternate route was considered for I-210 due to corridor geometry and congestion aspects. Thus, it was not necessary to score this alternate (Colorado/Foothill). Instead, it is retained as long as I-210 is retained as part of the corridor network.

## 8.4 SUMMARY

The results of ranking the alternate routes are summarized in Table 17, along with a relative retention priority indication (lowest number represents highest priority). The summary table is for later reference when configuring the alternative system designs.

Table 17. Summary of Alternate Route Ranking

Primary Route	Alternate Route	Alternate Route Score	Retention Priority *
I-10	Valley	71.0	1
	Garvey/Valley	66.5	1
	Mission/.../Arrow	48.0	3
	Mission/Hunt./I-210	59.0	2
Cal 60	Valley	59.5	1
	Garvey/Valley	67.0	1
I-210	Colorado/Foothill	---	1

\*Lowest number is highest priority

## SECTION 9

### ROADWAY NETWORK CONFIGURATIONS

#### 9.1 INTRODUCTION

In this section, the total set of candidate corridor roadways is examined for the purpose of developing several roadway network configurations. In general, the first configuration is taken as one containing all of the roadways. Each succeeding one is then established as a subset of the previous case. It is important, however, to recognize that each configuration should represent an identifiable IMIS network suitable for implementation of the IMIS concepts. The results then serve as the basis for the subsequent development of alternative system designs.

The inputs for this task consist of the map of the corridor showing the candidates remaining after the initial screening process, the results of route evaluation (ranking), and finally, a good working knowledge of the traffic operations in the corridor. The latter provides an input of judgement which is a necessary ingredient, since the configuration task cannot be treated solely as a mechanical process.

#### 9.2 NETWORK CONFIGURATIONS

The results of this task have been summarized in the form of corridor maps showing the roadways included in each configuration. Four networks were developed as shown in Figures 10 through 13. A single base map was used for all cases, with excluded roadways retained but shown as dotted lines.

The following overall considerations provided some initial guidance in establishing the gross geometric boundaries of the configurations:

- The most pronounced congestion problems fall in the south-west quadrant of the corridor
- There are congestion problems in the north-west quadrant of the corridor, but they are primarily in its upper eastern portion
- The entire eastern half of the corridor has minimal congestion.

Based on the above, the southwest quadrant was retained in all configurations, while portions of all other quadrants were subject to elimination in one or more of the configurations. The candidate networks are discussed further below.



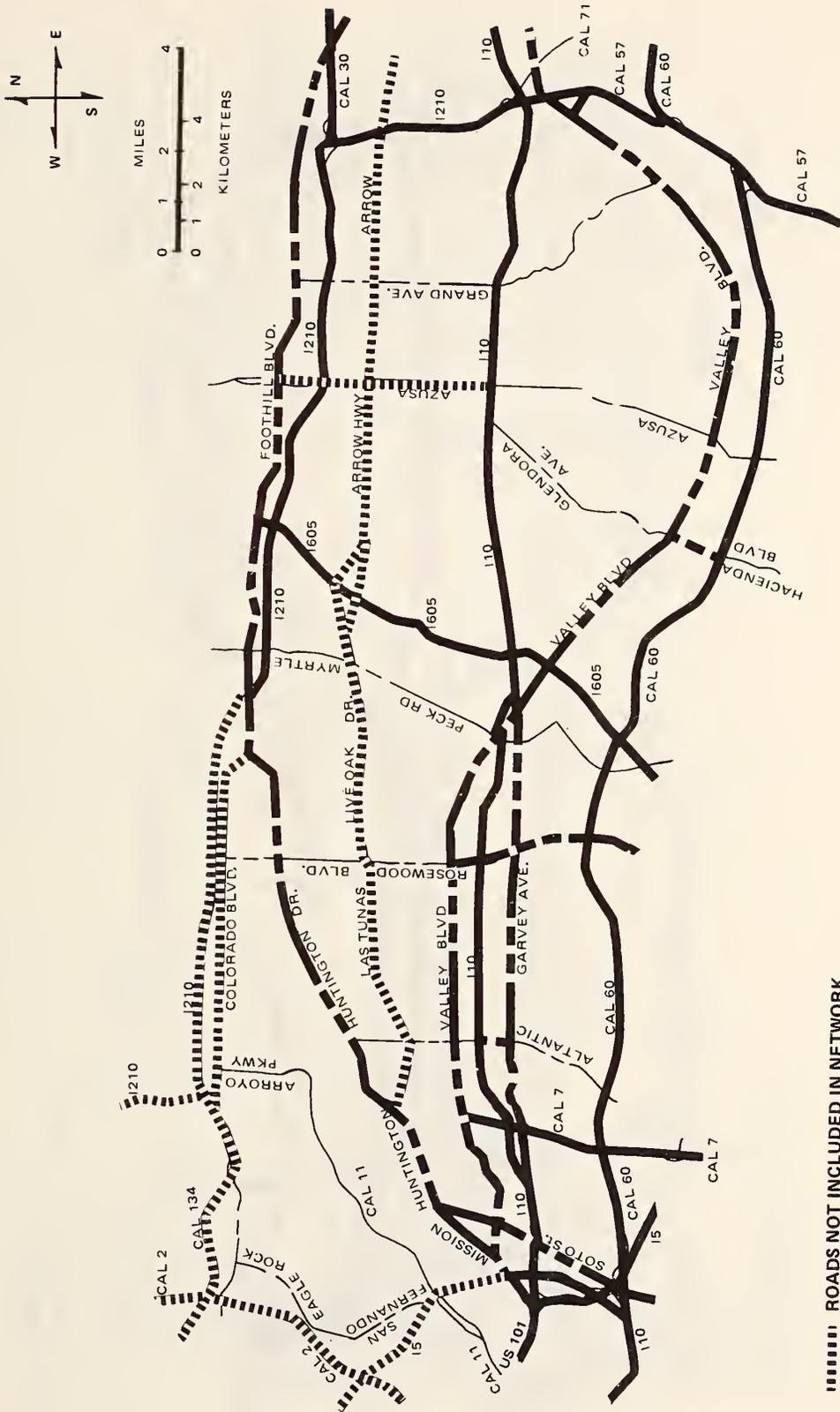


Figure 11. Network Configuration B

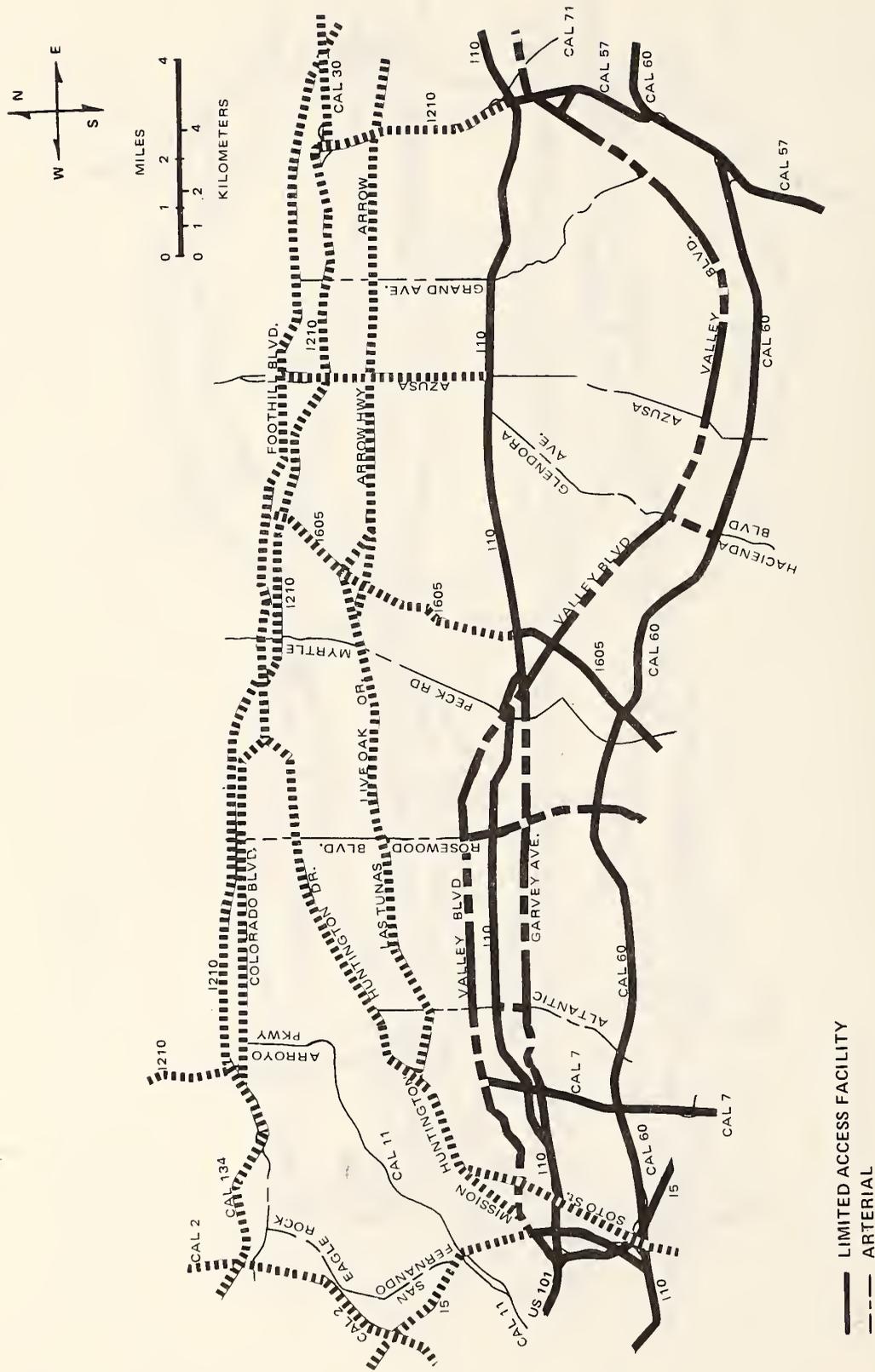


Figure 12. Network Configuration C



- Network Configuration A (Figure 10)

This is the baseline configuration, which, as noted earlier, contains all of the candidate roadways remaining after the initial screening process. As such, it will serve to provide a network candidate which has maximum cost, thus indicating an upper bound for a potential investment in the IMIS corridor.

- Network Configuration B (Figure 11)

This configuration contains the first change in the overall corridor boundaries, i. e., the removal of the upper western corner. The rationale involved consideration of two factors. First, there is little or no congestion on the portions of I-210, Cal 134, Cal 2, and I-5 in this area. Thus, the direct benefits are not likely to justify the capital and operating costs. Second, its utility as an alternate route for I-10 is severely handicapped because of the distance penalty.

In addition, the relatively low ranking of the Las Tunas/Live Oak/Arrow alternate route resulted in its exclusion from this network. Azusa Avenue was also excluded, since its utility was greatly diminished when the alternate route was eliminated.

- Network Configuration C (Figure 12)

As can be seen from the Figure, the remainder of the upper half of the corridor was excluded in this configuration. The reasoning applied here was similar to that indicated for Network B, i. e., the general lack of congestion and distance penalty when serving as an alternate route for the remainder of the corridor.

- Network Configuration D (Figure 13)

For the final network configuration, the eastern half of the remaining network was excluded. The absence of congestion was the governing factor. The remaining arterials and connectors in the western segment were all retained to provide maximum capability to achieve benefits in this most congested portion of the corridor.

### 9.3 DISCUSSION

The basic objective of developing a set of network configurations is to permit a series of preliminary system designs to be postulated and subsequently evaluated. The designs should provide a spectrum of costs, so that where a cost constraint exists it may be adequately considered. The major cost variations result from altering the network size; thus a minimum and maximum were developed as well as two intermediate cases. The configurations are geared more toward providing this spread in cost than towards finalizing any specific design.

The latter can be done after an appropriate preliminary system design is selected based on the benefit/cost evaluation. Variations can be made (and further evaluations performed if deemed necessary) once the "ballparks" are known.

It is noted that in this particular test corridor, its overall geometry and congestion locations were such that judgement played a heavy role in the development of the network configurations. For example, it appeared logical to the study staff to delete major portions of the corridor as a whole in progressing from one network to the next, more so than to treat each roadway on an individual basis.\* This may not be the case for another corridor. Thus, each situation must be examined on its own merits. The process is not mechanical - there is no substitute for good judgement.

---

\*It is, of course, possible that personnel more familiar with the corridor might have defined the network configurations somewhat differently.

## SECTION 10

### ESTABLISHMENT OF CONTROL AREA BOUNDARIES

#### 10.1 INTRODUCTION

In this section, the candidate networks are partitioned into subnetworks. The subnetworks are based on each having a common control philosophy related to the IMIS control functions of ramp metering, diversion, and traffic responsive arterial signal control.

As called for in the methodology, control probability factors are also assigned to each subnetwork to provide the basis for evaluating the real-time dynamic capabilities of IMIS. These factors represent the fraction of time that IMIS can be exercised in a subnetwork to obtain a net positive benefit. A control volume shift level is also computed in this section.

#### 10.2 CONTROL SUBNETWORKS

Typically, control subnetworks are established by partitioning a corridor along its lengthwise dimension in accordance with the control capability provided by the included roadways. At points where control capability changes, a new subnetwork is formed. The process continues until the entire length of the corridor has been treated, and subnetwork types have been assigned to each segment. Normally, partitioning is not done along the width dimension, since this tends to split a corridor into essentially two parallel corridors. The integrated operation of the overall corridor is better preserved and evaluated when treated as a single entity.

In the Handbook, three major subnetwork types are defined. Briefly, these are:

- Type 1 - The primary control function associated with this type is route diversion. Generally, diversion will be from one freeway to another, although freeway-to-arterial diversion (with responsive signal control on the arterial) is also included in this type.
- Type 2 - The primary control function for this type is ramp metering. Typically, this will be the case for a single freeway with an adjacent service road or nearly parallel arterial. Responsive signal control is included for the service road or arterial, and available capacity is assumed to be used by ramp "divertees". Thus freeway diversion is not considered as a primary control for this subnetwork type.

- Type 3 - This type affords the full complement of IMIS controls. Normally the roadway configuration will include at least two freeways and a service road or parallel arterial with responsive signal control.

In Section 9, four roadway network configurations were established for the study. The first (configuration A) included all of the candidate roadways remaining after the initial screening of routes. The remaining three configurations (B, C, and D) were progressively smaller subsets of the first. Thus, the selection of control subnetworks for the largest candidate inherently defines the subnetwork types for all candidates.

Based on the flow conditions established for the corridor roadways (from Section 7), the entire eastern half of the corridor (i. e., east of I-605) has minimal peak period recurrent congestion. Although the roadway network could support a "system" type of ramp metering in some areas, this treatment is not considered warranted. Thus, the only control function assumed for this part of the corridor is diversion. As such, the eastern half of the corridor has been classified as a Type 1 subnetwork.

The western half of the corridor has entirely different network and flow characteristics. The flow characteristics exhibit very pronounced peak period congestion problems resulting from traffic demands approaching roadway capacities along all three major freeways. Additionally, the close proximity of parallel arterials to the freeways provide good potential for ramp metering along each. For the I-10 and I-210 freeways, the potential for system-wide ramp metering is excellent. Thus the corridor portion west of I-605 is considered as a type 3 subnetwork for which the full complement of IMIS control functions can be applied.

Figure 14 illustrates the control area boundaries. The two types of subnetworks defined apply directly to the smaller roadway networks as well, since the same control function capability still exists (although at reduced levels). For the case of network configuration D, only the single type 3 subnetwork is applicable, since it does not include the eastern portion of the corridor.

### 10.3 SUBNETWORK CONTROL PROBABILITY FACTORS

The control probability factors account for variability in the traffic flow and represent the fraction of time that IMIS control can be exercised. Table 18 (reproduced from the Handbook) gives the standard set of factors associated with each subnetwork configuration type. For the western subnetwork, which is a standard type 3 configuration the control probability factors are .51, 1.0 and 1.0. These factors corresponding to operational conditions of peak period normal congestion, peak period incident congestion, and off-peak incident congestion, respectively.

The eastern subnetwork is a type 1 configuration; however, a modification is made to the standard control probability factors (as noted in Table 18) to account for the fact that the peak period normal congestion operating condition



Table 18. Typical Control Probability Factors\*

Subnetwork Type	Control Function	Roadway Operational Conditions		
		Peak Period Normal Congestion	Peak Period Incident	Off-Peak Period Incident
Type 1 Two or More Freeways	Diversion Only	.18	.3**	1.0
Type 2 Single Freeway With Service Road Or Arterial	Ramp Metering, Signal Control	.3	1.0	1.0
Type 3 Two Or More Freeways With At Least One Service Road Or Arterial	Diversion, Ramp Metering, Signal Control	.51	1.0	1.0

-----  
 \*This Table appears in the Handbook as Table 32.

\*\*In the present study a value of 1.0 has been used (see text Section 10.3).

does not exist over a significant area of the subnetwork's roadways. Therefore, the peak period incident control probability factor has been set to 1.0. The argument for making this modification is that the absence of normal peak period congestion implies that there will be some available capacity on the roadways. Thus, when an incident occurs during a peak period, there is a very high probability (set equal to 1.0) that diversion control can be exercised almost always, resulting in a positive benefit.

#### 10.4 CONTROL VOLUME SHIFT LEVEL

In Section 7, the variability coefficient (or standard deviation,  $\sigma_Q$ ) for the control probability model was found to be approximately 125 vehicles/lane/hour. As indicated in the Handbook, the mean volume shift available for control ( $\Delta Q$ ) is computed as  $3/2 \sigma_Q$ , or approximately 185 vehicles/lane/hour. This value of  $\Delta Q$  is used for the freeways in Section 15 to determine the overall control volume shift for a given network configuration.

## SECTION 11

### REVIEW OF SYSTEM FUNCTION AND CONTROL POLICY

The outputs of the preceding steps in the methodology have provided all of the technical data needed to begin the configuration of the alternative system designs. Prior to commencing that effort, it is considered prudent to perform a review of the system function and control policy. As noted in the Handbook, the objectives here are:

- To assess jurisdictional preferences regarding implementation of control functions
- To determine jurisdictional constraints regarding selection of roadways for the corridor network
- To determine requirements and constraints for interfacing with existing traffic surveillance and control systems
- To verify that IMIS will support local transportation policy

Conceivably, the above factors could influence the system design, and thus, to avoid later rework, it has been suggested that the policy review be accomplished at this point in the study.

For the purposes of the present report, it has been assumed that no changes are required to the foregoing work, since the study staff by itself is not in a position to perform the review. There is no impact on the overall methodology testing, since this aspect is one for which "validation" is not applicable.

## SECTION 12

### EQUIPMENT SELECTION FOR IMIS SUBSYSTEMS

#### 12.1 INTRODUCTION

The purpose of this task of the methodology is to select suitable equipment for the IMIS subsystems so that representative cost data can be developed. The extent of the trade-off studies is left to the judgment of the using agency. The Handbook provides the alternative of bypassing any or all of the trade-off studies and basing the cost data on typical equipment. (This alternative has been used in the present study.)

#### 12.2 EQUIPMENT AND UNIT COSTS

The following subject areas are treated in this task:

- Variable Message Signs
- Fixed Message Signs
- Highway Advisory Radio
- Entrance Ramp Control
- Freeway Surveillance
- Arterial Surveillance and Control
- Other System Surveillance
- Motorist Aid Callboxes
- Pre-Trip/Enroute Information Services
- Equipment Cabinets

The communications and control center areas are treated in Section 13 since their requirements are dependent on the overall system configurations.

##### 12.2.1 Variable Message Signs (VMS)

Variable Message Sign configurations (and thus costs) can vary from location to location within an IMIS corridor, depending on the functional requirements of the sign and roadway geometry. Because these signs can represent a major system cost item, an attempt is made to take this variation into account.

The Handbook suggests a generic configuration which should satisfy most of the freeway diversion point requirements. This configuration provides for two signing stations approaching each diversion point. The first station, located 1/2 to 1 mile (0.8 to 1.6 km) upstream, contains a suitably mounted multi-line VMS which provides traffic conditions and alternate routing information (when appropriate). The second station, at the approach to the diversion point, consists of one or more single-line VMS inserts incorporated into the normal fixed guide signing, to serve as confirmation for the upstream VMS. This concept is illustrated in Figure 15. For arterials, a single VMS signing station is usually adequate.

Following the Handbook procedures, a map was prepared showing the candidate VMS locations (diversion points) and the number of lanes in the given flow direction. (See Figure 16. The figure also includes highway advisory radio locations for later use.) The lane information is needed in conjunction with estimating sign mounting requirements.

Next each location was reviewed to estimate the number of lines for the main VMS, the type/size of support structure required, and the number of VMS inserts required. The results are recorded on the worksheets shown as Table 19. From this table, the following 5 signing configurations were identified:

- Configuration A:

- 3-line VMS on sign bridge, 2 one-line VMS inserts on sign bridge, (29 locations)

- Configuration B:

- 3-line VMS on sign bridge, 3 one-line VMS inserts on sign bridge (2 locations)

- Configuration C:

- 4-line VMS on sign bridge, 2 one-line VMS inserts on sign bridge (2 locations)

- Configuration D:

- 4-line VMS on sign bridge, 3-one-line VMS inserts on sign bridge (1 location)

- Configuration E:

- 2-line VMS on cantilever support (15 locations)

Each sign location (I. D. number) is cross-referenced to its configuration in Table 20. The I. D. numbers correspond to the map locations shown in Figure 16.

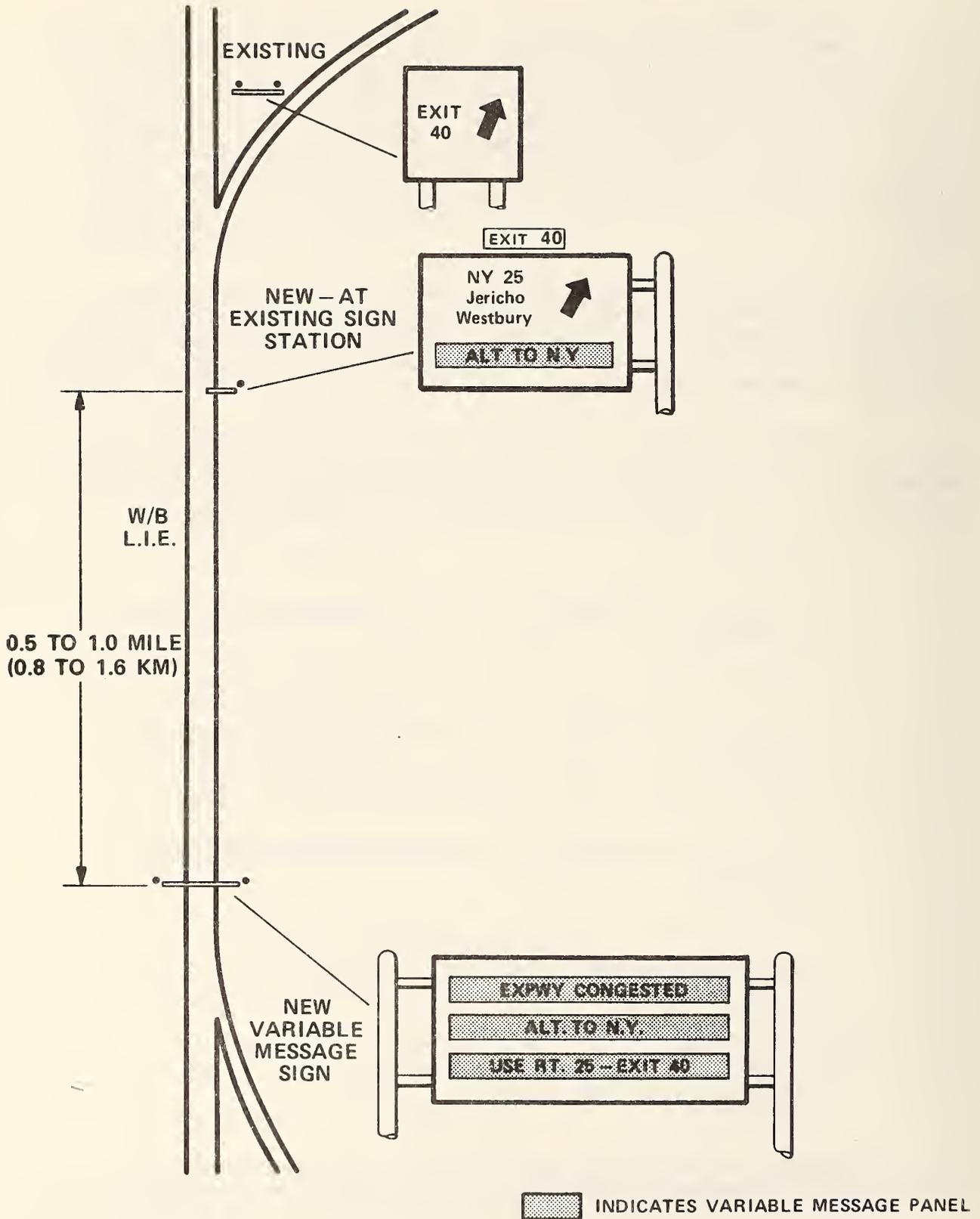


Figure 15. Typical Signing Configuration

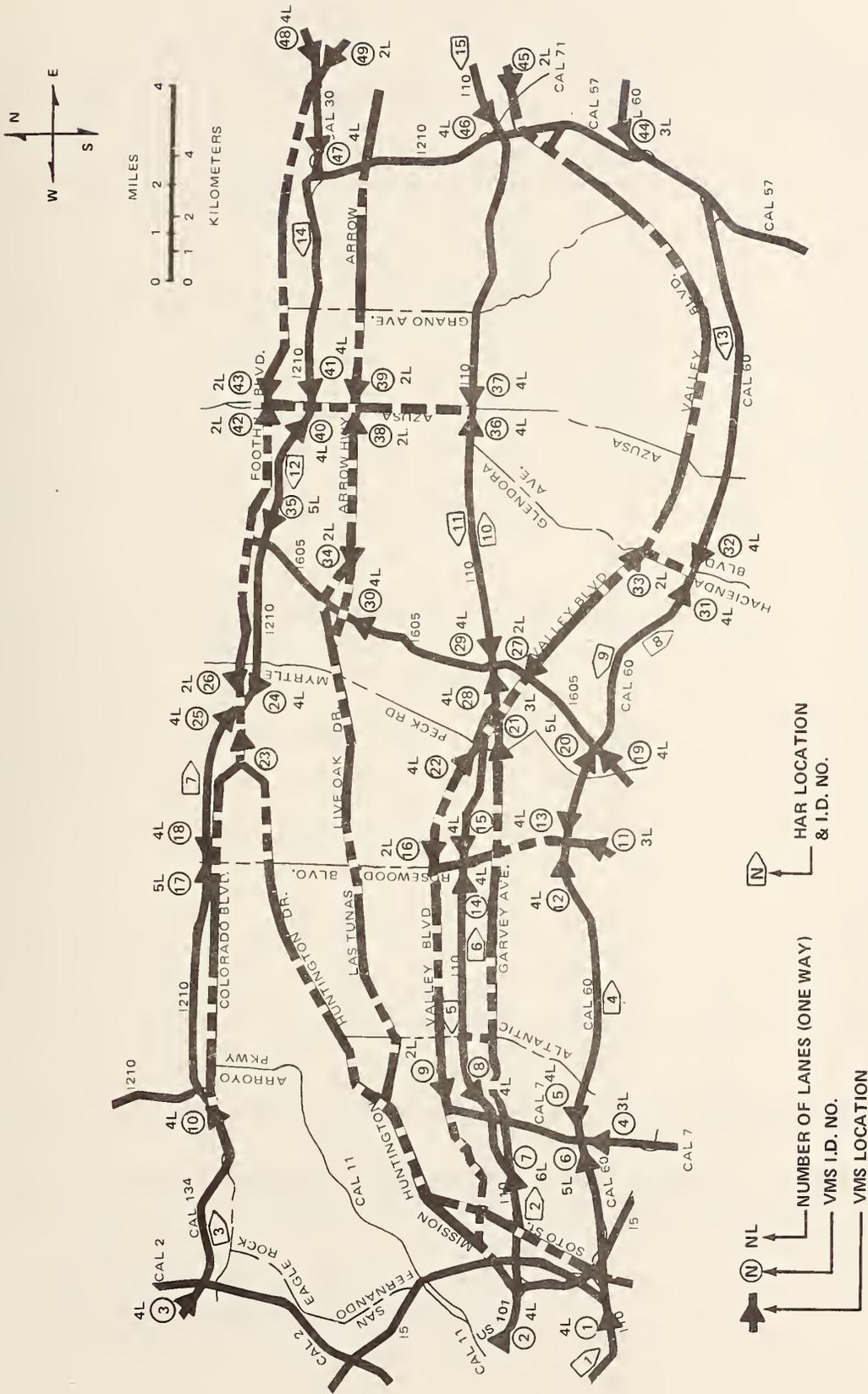


Figure 16. Candidate Variable Message Sign and Highway Advisory Radio Locations

Table 19. Worksheet for Estimating Number of Different Signing Configurations

Location I. D. Number	Multi-Line Variable Message Signs				Type of Support Required			Number Req'd	Variable Message Inserts		
	No. of Lines Required		Type of Support Required		Cantilever	Bridge	Roadside		Existing Support Type		Roadside
	2-Line	3-Line	4-Line						Bridge	Cantilever	
1											
2		✓			✓			2	✓		
3		✓			✓			2	✓		
4		✓			✓			2	✓		
5		✓			✓			2	✓		
6		✓			✓			2	✓		
7		✓			✓			2	✓		
8							✓	2			
9							✓	0			
10								0			
11								0			
12		✓			✓			3	✓		
13		✓			✓			3	✓		
14		✓			✓			2	✓		
15		✓			✓			2	✓		
16							✓	0			
17								2	✓		
18								2	✓		
19								2	✓		
20								2	✓		
21		✓			✓			0			
22		✓			✓			0			
23		✓			✓			0			
24								0			
25		✓			✓			2	✓		
26		✓			✓			0			
27								0			
28								2	✓		
29								2	✓		
30								2	✓		
31								2	✓		
32								2	✓		
33		✓			✓			0			
34		✓			✓			0			
35								2	✓		
36								2	✓		
37								2	✓		
38		✓			✓			0			
39		✓			✓			0			
40								2	✓		
41		✓			✓			2	✓		
42		✓			✓			0			
43								0			
44								0			
45		✓			✓			2	✓		
46		✓			✓			0			
47		✓			✓			2	✓		
48		✓			✓			2	✓		
49								0			

Table 20. VMS Sign Configurations

Sign I. D. No.	Configuration I. D.	Sign I. D. No.	Configuration I. D.
1	C	26	E
2	A	27	E
3	A	28	A
4	A	29	C
5	A	30	A
6	A	31	A
7	D	32	A
8	A	33	E
9	E	34	E
10	A	35	A
11	E	36	A
12	B	37	A
13	B	38	E
14	A	39	E
15	A	40	A
16	E	41	A
17	A	42	E
18	A	43	E
19	A	44	A
20	A	45	E
21	E	46	A
22	E	47	A
23	E	48	A
24	A	49	E
25	A		

-----  
Sign ID Nos are defined in Figure 15

Configuration IDs are defined in the text

The remainder of this task is related to developing the unit cost data (capital, operating, and maintenance) which corresponds to the configurations defined above.

#### A. Capital Costs

For the purposes of illustration, sign type in this application has been assumed to be the disc matrix VMS. The total capital cost consists of two components; the cost of the sign itself, and the cost of the mounting structure, the latter including all necessary installation, guard rail, conduit, incidentals, etc. Sign costs, based on Handbook values are as follows:

2-Line	\$33,000	}	18 inch (46 cm) characters, 20 characters per line
3-Line	\$48,000		
4-Line	\$62,000		
1-Line Insert	\$11,500		(includes \$9,000 for 10 character sign plus \$2,500 for new guide sign panel)

Costs for the mounting structures were estimated to be the following:

	<u>To Span</u>	<u>Installed Cost</u>
Sign bridge	3-lanes	\$42,000
	4-lanes	46,000
	5-lanes	51,000
	6-lanes	57,000
Cantilever support		18,000

New signs bridges are required for the multi-line VMS installations. For the case of the 1-line VMS inserts in guide signs, the new panels will be larger in some cases than the previously used ones, and the existing sign bridges may have to be replaced. Therefore the following assumptions were made: sign configurations B and D, which contain 3 revised panels, will require a new sign bridge, and for configurations A and C, a new sign bridge will be required in 50 percent of the cases.

The configuration cost can now be calculated, based on the above costs and assumptions. Configuration A includes 3, 4 and 5 lanes cases. Also, for half of the cases, 1 new sign bridge will be required, while for the other half, 2 new bridges will be required.

Corresponding costs, then, are as follows:

<u>Configuration A</u>	<u>1 Bridge Req'd.</u>	<u>2 Bridges Req'd.</u>
3-Lane	\$113K	\$155K
4-Lane	117K	163K
5-Lane	<u>122K</u>	<u>173K</u>
Average	117.4K	163.8K

Example: Sign Cost: \$48K (multi-line) + 2 inserts @ \$11.5K = 71K

3 Lane Bridge (1): 42K

113K

for 2 Bridges add \$42K 42K

155K

A composite average for Configuration A is \$140.6K. This value may be used later in developing cost for alternative systems. For example, if 5 configuration A signs are removed in an alternative design, the capital signing cost deleted would be 5X \$140.6K or \$703K.

Following the above procedures, the resulting capital costs for all signing configurations are summarized below:

<u>Configuration</u>	<u>Total Capital Costs</u>		
	<u>1 Bridge Req'd.</u>	<u>2 Bridges Req'd.</u>	<u>Composite Average</u>
A	\$117.4K	\$163.8K	\$140.6K
B	-	174.5K	174.5K
C	131.0K	177.0K	154.0K
D	-	210.5K	210.5K
E	51K (Canti- lever)	-	51K

#### B. Annual Maintenance Costs

For the disc matrix sign, the Handbook value (based on discussions with a sign manufacturer) for annual sign maintenance is 3 percent of the capital cost of the sign itself (i. e., not including the support costs). Thus, for each configuration, the annual maintenance costs are estimated as:

<u>Configuration</u>	<u>Annual Maintenance</u>
A (3% of \$71K)	\$ 2.13K
B (3% of \$82.5K)	2.48K
C (3% of \$85K)	2.55K
D (3% of \$96.5K)	2.90K
E (3% of \$33K)	0.99K

### C. Annual Operating Costs

For the disc matrix sign, the only significant operating cost is that of power for external illumination of the signs during periods of darkness. The following assumptions were used for calculating the operating costs:

- 2-line VMS requires 800 watts
- 3 & 4-line VMS required 1200 watts
- Insert panel requires 600 watts
- illumination required for 12 hours/day
- cost of power is \$.08 per Kilowatt-hour (KWH)

As a sample calculation, consider configuration A. This configuration requires 1200 watts for the 3-line VMS, plus 600 watts for each of the 1-line VMS inserts. Thus the total is 2400 watts (2.4KW). The annual cost is then:

$$2.4 \text{ KW} \times 12 \text{ hrs/day} \times 365 \text{ days/yr} \times \$.08/\text{KWH} = \$840.96 \text{ per year}$$

Following this procedure, the annual operating costs for all configurations are summarized below:

<u>Configuration</u>	<u>Annual Operating Cost</u>
A	\$ 841.00
B	1,051.00
C	841.00
D	1,051.00
E	280.00

The above concludes the development of the unit cost data for the variable message signs.

### 12.2.2 Fixed Message Signs

Two categories of fixed signing are included as part of the IMIS design. The first is termed "route guidance/route confirmation". The purpose of this category is to insure that all alternate routes used in conjunction with a diversion from a freeway are adequately signed to provide a well defined path for the diverting motorists. Typically, roadside mounted guide signs and trailblazer assemblies can serve this purpose. Driving the alternate routes and noting where existing signing must be augmented for this purpose is one method of determining the new signing requirements.

The second category of fixed signing is termed "system identification" signing. The purpose of this category is to inform the motorist of the existence and extent of IMIS (similar to those used for motorist aid call box systems). Typically these are located at key entry points to, and exit points from, the IMIS corridor. Requirements can be determined basically from a corridor map.

Since the route guidance/route confirmation signing is not a major system cost, the Handbook provides an alternative for approximating these costs, i. e., to use a value such as \$500 per corridor mile (\$311 per corridor kilometer) as a "lump sum" figure. This value has been adopted for the present study.

For the system identification signs, a unit cost estimate of \$1000 per sign has been assumed.

For both of the above signing categories, annual maintenance and operating costs have been assumed to be negligible.

### 12.2.3 Highway Advisory Radio

Highway Advisory Radio (HAR) is an additional or alternative method of providing motorists with real-time traffic information. Transmitters, located at roadside, broadcast information provided from the central control facility to a localized zone along the roadway, at frequencies which can be received on the motorists AM radio. (The frequencies allocated, 530 KHz and 1610 KHz, fall just outside of the standard AM broadcast band).

A discussion of HAR equipment and trade-off factors is contained in the Handbook. The major trade-off factor is the type of antenna used, i. e., monopole or cable radiator. For urban roadway applications, the general consensus is that the cable radiator should be used because of its well defined zone of coverage and substantially smaller likelihood of causing interference with other radio equipment.

Typical unit costs for a roadside radio installation, including related equipment at central, are contained in the Handbook and are used in the present study. These unit costs are:

Capital	\$20,000
Annual Maint.	2,500
Annual Ops	200

#### 12.2.4 Entrance Ramp Control

The predominant form of ramp control in an IMIS corridor is entrance ramp metering. Ramp metering concepts, trade-off factors, and equipment complements are discussed in the Handbook. Basically, it is expected that system-wide responsive metering (as opposed to pre-timed or local responsive) will be used in IMIS. Also, the most common technique for releasing vehicles from the ramp is the single lane, one-vehicle-at-a-time method.

Based on the above, the Handbook provides unit cost estimates of a ramp metering installation. These values, which are adopted for the present study are:

Capital	\$14,050
Annual Maint.	400
Annual Ops.	120

#### 12.2.5 Freeway Surveillance

Automatic surveillance equipment is installed on all freeways (mainline and ramp) in the IMIS corridor to provide the real-time traffic parameters required for system operation. The Handbook discusses the equipment trade-off and equipment spacing aspects, and recommends the following configuration be used for the feasibility study:

- Detector type - Inductive Loop
- Freeway Detector Station - At a given location, all lanes are instrumented
- Freeway Detector Station Spacing - One station every 1/2 mile (0.8 km)
- Freeway Double Detector Station - One double station every 5 miles (8 km). The double stations, sometimes referred to as "trap" configurations, provide accurate speed and classification data at these sites.
- Non-Metered Ramp Detector Station - One detector per ramp. (Metered ramps were treated separately in the previous paragraph).

The estimated unit cost data provided in the Handbook is used in the present study. The costs are as follows:

- Unit Capital Costs

Freeway Detector Station	\$1,000/lane
Add for Double Station ("trap")	800/lane
Unmetered Ramp	1,100/ramp

- Unit Maintenance Costs

Freeway Detector Station	\$40/lane/year
Add for Double Station ("trap")	40/lane/year
Unmetered Ramp	40/ramp/year

- Unit Operating Costs

Freeway Detector Station	\$ 7/lane/year
Add for Double Station ("trap")	7/lane/year
Unmetered Ramp	7/lane/year

#### 12.2.6 Arterial Surveillance and Control

There are three basic areas treated in this section of the study, i. e. :

- Arterial Control Approaches
- Critical Intersection Control (CIC) and Surveillance
- Arterial Surveillance, non-CIC

The following is a brief summary of the Handbook recommendations for each of the above as related to the feasibility study:

- For arterial control, assume that each signalized intersection will be controlled by the central computer
- For each CIC (as determined by judgement or the procedures provided), all lanes on all intersections approaches are instrumented with detectors

- For non-CIC cases, detector stations are provided (all lanes instrumented) at a density of either one station per signalized intersection per approach along the arterial, or one per mile (per 1.6 km) per direction, whichever is less.

The unit costs for arterial surveillance and control are based on the values provided in the Handbook, and are shown in Table 21. As noted in the Handbook, the costs for arterial surveillance are dependent on the IMIS communications medium. This dependence is due to the need to connect the controllers and detectors to a cabinet containing telemetry equipment. If an owned cable is used as the system communications medium, a major portion of the trenching costs are attributed to the communications subsystem. If other than owned cable is used, the full cost of arterial trenching must be borne by the arterial surveillance function. In the present study, the owned cable has been assumed, and the costs given in Table 21 represent this case.

Table 21. Arterial Surveillance and Control Unit Costs

A. ARTERIAL SURVEILLANCE (1)		
	PER CIC*	PER NON-CIC*
● Capital Cost	\$27,500	\$ 2,500
● Maintenance Cost	400	100
● Operating Cost	90	20
B. ARTERIAL CONTROL (2)		
● Capital Cost	\$500/intersection	
● Maintenance	\$50/intersection	
● Operating Cost	(Negligible)	
(1) Costs are average of two-lane and three-lane (per direction) arterial cases. Difference for either is within 5 percent for capital costs. Differences for maintenance and operations costs may be neglected.		
(2) Assumes central control approach and use of existing controllers. Costs are for controller/communications interface units. Communications and cabinet costs are treated separately elsewhere.		
*Each CIC cost includes all approaches. Non-CIC costs are per detector station for one flow direction.		

## 12.2.7 Other System Surveillance

It is possible that other manual surveillance techniques can be used in IMIS to augment the automatic surveillance system. Typically, these could include closed circuit television, ground patrolling vehicles, helicopters (or fixed wing aircraft) and citizen's band radio. In this section, these techniques are addressed as they relate specifically to the test corridor.

### A. Closed Circuit Television (CCTV)

In general, overall CCTV coverage in an IMIS corridor cannot be justified on a benefit/cost basis. Even on an isolated coverage basis it is difficult to justify because (1) most of the achievable benefits are accrued by the automatic surveillance subsystem, (2) equipment, installation, and maintenance costs are high, and (3) wideband communication facilities (e.g. coaxial cable or microwave) which are not required for any other IMIS function, would have to be provided. It is recognized, however, that there may be special circumstances, which in the judgement of the operating agency, warrant inclusion of some CCTV coverage. In the present study, it has been assumed that such special circumstances do not exist, and thus, CCTV is not included in the system.

### B. Ground Patrolling Vehicles

As noted in the Handbook, the purpose here is to determine whether additional ground patrolling vehicles (i. e. police cars or tow trucks) should be considered as part of IMIS. Due to the complexities involved in a rigorous quantitative analysis, the Handbook suggests that the decision be based on judgement, considering the present patrolling complement and adequacy of response times.

Based on discussions with cognizant personnel in the test corridor, heavy police patrolling presently exists on Cal 60 and very heavy patrolling exists on I-10. I-210 is patrolled but not heavily, primarily because more vehicles are not warranted for the existing traffic conditions. Average response times to accidents with present procedures and equipment are quite good, as evidenced by the estimates below:

Officer arrival:	6-8 minutes
Official tow call to tow notified:	2-3 minutes
Tow arrival:	13 minutes
Total Response Time: Approx.	23 minutes

On the basis of the above, the further addition of ground patrolling vehicles does not appear to be warranted.

### C. Aircraft Surveillance

The use of aircraft dedicated solely to traffic surveillance cannot be justified in IMIS, especially in the presence of the automatic surveillance system. Often, however, some aircraft surveillance does exist (typically during peak hours), provided either by commercial radio stations or the police. In this case, it is desirable to coordinate the operations with the IMIS control center. For example, if the automatic incident detection capability in IMIS detects an incident, its location can be transmitted to a patrolling police helicopter, which in turn, can then rapidly reach the scene and determine the type of problem and services needed.

The California Highway Patrol has one helicopter and several fixed wing aircraft. As noted above, a telephone communication link between the police dispatcher and the control center should be provided to coordinate operations. Costs for this link are small enough to be considered negligible in the study.

### D. Citizen's Band (CB) Radio

As noted in the Handbook, it is not considered desirable for the IMIS control center to interface directly with public CB radio operators. Rather, any interface should be with the police, who generally obtain information from volunteer groups or, in some cases, through direct monitoring of certain CB channels.

There is, however, a potential use of CB which is currently being evaluated in the Chicago area. This consists of installing CB receivers at intervals along the freeway with a communication link back to the central facility. When an incident is detected by the automatic surveillance system, the nearest receiver is energized to "listen in" on the appropriate channel. Normally, the mobile CB users in the area will be discussing any problem and providing each other with information on the location, type and severity of the incident, lanes open, length of back-up, etc. This information could be useful at the control center. Because this approach is still in the evaluation stage, it is premature to recommend its inclusion in the test corridor. In future studies, however, it should be considered if the evaluation produces positive results.

#### 12.2.8 Motorist Aid Callbox Subsystem

A motorist aid callbox subsystem for the major freeways in a corridor is an integral part of IMIS. Such a system, however, already exists in the test corridor. This being the case, the Handbook identifies two options: (1) to retain the system as is, but provide a communication link between the responding agency and the IMIS control center, or (2) to modify the system so that it uses the IMIS communications facilities instead of its present medium, if this will result in a significant operating cost savings.

The existing subsystem uses leased phone company lines, whereas the IMIS communications medium to be assumed for the present study is owned cable. Thus, there is potential for cost saving in the corridor if the owned cable is used

along the freeways for the motorist aid function. To determine the estimated savings, it would be necessary to discuss the matter with the involved telephone company or companies. Then, if the savings are significant, and there are no other reasons to preclude the switchover, the cost saving could be applied to IMIS in the feasibility study.

For the present study, involvement with the telephone company in the test corridor for a hypothetical case was not considered warranted. Instead, it has been assumed that the existing motorist aid subsystem will be retained as is, and no cost will be attributed for this function.

### 12.2.9 Pre-trip/Enroute Information Services

Four categories of pre-trip/enroute information services are included in IMIS, as discussed in the Handbook. Briefly, these are:

- General information - This takes the form of printed material (e.g., a brochure), and serves to educate the public about the functions and potential benefits of IMIS.
- Telephone dial-up system - Motorists can call special phone numbers to obtain current traffic conditions in the corridor.
- Radio and TV broadcasts - Through a communications link between the control center and the participating stations, the stations can be provided with applicable traffic information for broadcast to their listening public.
- Recreational facilities - Standard telephone communications between major recreational facilities and the control center can be used to provide information for public address announcements or scoreboard display when warranted by traffic conditions.

Unit cost estimates for these services, as contained in the Handbook, are as shown in Table 22.

With regard to the dial-up telephone, the number of lines required, based on the "rule-of-thumb" given in the Handbook, is calculated below:

Average ADT's -	I-10	150,000
	Cal 60	150,000
	I-210	100,000
	Total	<u>400,000</u>
Calls/day =	2 percent of ADT = 8,000	
Line Capacity =	200 calls/day	
Lines Required =	40	

The above is used later in calculation of system costs.

Table 22. Pre-Trip/Enroute Information Cost Data

Information Service	Cost Element	Estimated Cost		
		Capital	Maint.	Oper.
Brochure	4 pages, 1/2 million copies	\$25,000	---	---
Dial-up Telephone	leased line, each	---	---	\$600/yr.
Radio/TV	<u>IMIS Central:</u>			
	Modems, each station	\$ 1,000	\$120/yr.	negl.
	Computer interface	\$ 5,000	\$600/yr.	negl.
	Computer programming	\$10,000	---	---
	<u>Radio/TV Station:</u>			
	Modem	\$ 1,000	\$120/yr.	negl.
	CRT Terminal	\$ 3,000	\$360/yr.	negl.
	Printer	\$ 3,000	\$360/yr.	negl.
	Leased line, per station	---	---	\$600/yr.
Recreational Facility	Leased line, per facility	---	---	(assumed existing)

#### 12.2.10 Equipment Cabinets

Because of the geographic extent of IMIS, a large number of field equipment cabinets is required, and thus this becomes a substantial cost item. The average capital cost given in the Handbook (\$1,250) is used for the present study. This value is based on a mix of 20 percent large cabinets (\$1,800) and 80 percent small cabinets (\$1,100). Maintenance costs for cabinet knockdowns are estimated at \$1,500 each. Operating costs are neglected.

## SECTION 13

### DEVELOPMENT OF ALTERNATIVE PRELIMINARY SYSTEM DESIGNS

#### 13.1 INTRODUCTION

At this point in the study, the configuration of the alternative system designs is started. The four roadway networks developed in Section 9 provide the basis for the system configurations. In each case, two designs will be stipulated, one containing a full equipment complement, the other a minimal complement. In this way, eight alternative designs are produced, covering a wide spectrum of potential investments in IMIS.

The recommended procedure is to develop the largest and most versatile system first, and then, through appropriate reductions in roadways and equipment develop the remaining candidates.

#### 13.2 CANDIDATE A1

This candidate is the largest system and is based on roadway network A with a full complement of equipment. The related subsystems are discussed below.

##### A. Variable Message Signs

VMS locations for the full network and all candidate diversion points were specified earlier in Section 12. They are shown now in Figure 17. (This figure will also serve for Candidate A2 since the same roadway network is involved. Appropriate changes in equipment are identified on the figure for the latter candidate. Highway advisory radio locations are also shown.) This candidate contains 49 VMS locations.

##### B. Fixed Signing

For the route guidance/route confirmation signing, specific locations and quantities were not specified; rather, the Handbook alternative of using the "lump sum" cost approach was used. For system identification signing, one sign was assumed for each direction of each of three major east-west freeways to indicate system existence, etc. A similar number was used for the "end of system" signs. Therefore a total of 12 signs is included in this candidate.

##### C. Highway Advisory Radio

Following the location guidelines given in the Handbook, the HAR complement was specified (already shown in Figure 17). Only 15 locations are included in this candidate because of the high density of variable message signs.



#### D. Entrance Ramp Control

The determination of the number of ramps to be metered was done on a qualitative basis. The following assumptions were used:

- For the portion of the corridor east of I-605 there is insufficient congestion to warrant any significant amount of ramp metering. Therefore, it was assumed that there would be no metering in the eastern half of the corridor.
- Based on general considerations of congestion locations, plus assumed inability to meter some ramps (e.g. due to high speeds, geometrics, storage available) the following percentages of ramps in the western portion of the corridor were used to estimate the number of metered ramps: 75 percent for I-10, I-5 and Cal 60; 50 percent for I-210 and I-7, 25 percent for I-605 and Cal 2.

As a result of the above assumptions, the following numbers of metered ramps, by roadway, resulted (numbers of non-metered ramps are also shown):

<u>Roadway</u>	<u># of Metered Ramps</u>	<u># of non-metered Ramps (Entrance Plus Exit)</u>
I-10	32	108
Cal 60	29	101
Cal 57	0	10
I-210	21	119
Cal 30	0	0
I-605	3	37
Cal 7	2	8
Cal 2	1	15
I-5	9	31
TOTALS	97	429

#### E. Freeway Surveillance

In this candidate system, the freeway surveillance includes 1/2 mile (0.8 km) spacing for the mainline. Non-metered ramps (1 detector per ramp) are also included under the freeway surveillance topic. Table 23 provides a summary of the number of detectors, by roadway, for this candidate.

Table 23. Freeway Surveillance Requirements (Candidate System A1)

Road	Freeway Mainline										Non-Metered Ramps Total No. of Detectors
	Roadway Miles Per Configuration			Total Miles	No. of Detector Stations	Additional Stations For "Traps"	Total No. of Detectors				
	3-Lane	4-Lane	5-Lane					6-Lane			
I-10	-	19.0	4.4	3.2	26.6	106	10	512	108		
Cal 60	-	20.5	2.7	2.0	25.2	101	10	471	101		
Cal 57	-	3.2	-	-	3.2	13	2	60	10		
I-210	-	22.9	6.5	-	29.4	118	12	546	119		
Cal 30	-	2.7	-	-	2.7	11	0	44	0		
I-605	-	8.4	-	-	8.4	34	4	152	37		
Cal 7	3.2	-	-	-	3.2	13	2	45	8		
Cal 2	-	3.6	-	-	3.6	14	2	64	15		
I-5	2.1	2.0	-	-	4.1	16	2	63	31		
<b>TOTALS</b>	<b>5.3</b>	<b>82.3</b>	<b>13.6</b>	<b>5.2</b>	<b>106.4</b>	<b>426</b>	<b>22</b>	<b>1957</b>	<b>429</b>		

Note: 1 Mile = 1.61 km

## F. Arterial Surveillance

Surveillance requirements for both critical and non-critical intersections are provided, by roadway, in Table 24. It was estimated that the average intersection spacing was .75 miles (1.2 km). This value, together with each roadway length, was used to determine the number of signalized intersections, and then the number of detectors.

The number of critical intersections (13) was determined from discussions with cognizant signal operations personnel in the test corridor. The critical intersections identified were:

Colorado and Rosemead  
Huntington and Rosemead  
Valley and Rosemead  
Glendon and Rosemead  
Marshall and Rosemead  
Garvey and Rosemead  
Cal 7 and Valley  
Valley/Temple and I-605  
Arrow and Azusa  
I-10 and Azusa  
Gale and Hacienda  
Cal 60 and Hacienda  
Foothill and Damien

## G. Pre-Trip/Enroute Information Services

In this candidate, all services listed previously in Section 12 are assumed included. It is assumed further that there will be 4 participating radio (or TV) stations (to be used later for system cost estimating purposes).

## H. Communications

It is assumed in this study that an owned cable will be used as the communications medium. The cable will run along both sides of the freeways and along one side of the arterials. Further, a high degree of local (field)

Table 24. Arterial Surveillance Requirements (Candidate System A1)

Road	Length Miles	No. Signal Intersection*	No. CIC	No. Non-CIC	No. Art. Det. Sta. (Non-CIC)	No. Non-CIC Detectors	No. of CIC Detectors
Valley Blvd.	28.6	38	3	35	70	168	30
Garvey Ave.	8.8	12	1	11	22	56	10
Mission Rd.	2.6	3	0	3	6	12	0
Huntington Dr.	15.2	20	1	19	38	116	12
Las Tunas/Live Oak/ Arrow	21.0	28	1	27	54	114	12
Colorado Blvd.	7.9	11	1	10	20	40	10
Foothill Blvd.	10.0	13	1	12	24	48	8
Atlantic Blvd.	0.6	1	0	1	2	4	0
Rosemead Blvd.	2.8	4	2	2	4	12	20
Azusa Ave.	4.1	5	2	3	6	16	16
Soto St.	2.4	3	0	3	6	12	0
Hacienda Blvd.	1.0	1	1	0	0	0	8
TOTALS	105.0	139	13	126	252	598	126

\*Number of signalized intersections based on estimated average intersection spacing of .75 miles (1.2 km)

Note: 1 mile = 1.61 km

processing is assumed, along with a time-division multiplexing (TDM) polling approach.

Other configurational aspects include the number of communications units required and the cable size. In accordance with the Handbook procedures, every third field equipment cabinet is designated as a "telemetry cabinet", and each of these contains a communications unit. For freeways, the number of field equipment cabinets is computed as the sum of the number of detector stations and ramps (entrance and exit). For arterials, the number of cabinets is taken as 1 per intersection. Tables 25 and 26 present the results of the computations by roadway, for the freeways and arterials, respectively. The total number of field cabinets for this candidate system is 1,092 and the total number of communications units is 367.

The Handbook procedure for estimating the number of cable pairs required is indicated below (the steps are performed for each roadway). Note that for the freeways, only one flow direction is considered to establish cable

Table 25. Number of Field Cabinets and Communication Units, Freeways (Candidate System A1)

Road	No. of Freeway Detector Stations	No. of Ramps (Entr & Exit)	No. of Cabinets Req'd	No. of Communication Units Req'd
I-10	106	140	246	82
Cal 60	101	130	231	77
Cal 57	13	10	23	8
I-210	118	140	258	86
Cal 30	11	0	11	4
I-605	34	40	74	25
Cal 7	13	10	23	8
Cal 2	14	16	30	10
I-5	16	40	56	19
Totals	426	526	952	319

Table 26. Number Of Field Cabinets and Communication Units, Arterials (Candidate System A1)

Road	No. Signalized Intersections	No. of Cabinets Req'd	No. of Comm Units Req'd
Valley Blvd.	38	38	13
Garvey Ave.	12	12	4
Mission Rd.	3	3	1
Huntington Dr.	20	20	7
Las Tunas/Live Oak/Arrow	28	28	9
Colorado Blvd.	11	11	4
Foothill Blvd.	13	13	4
Atlantic Blvd.	1	1	1
Rosemead Blvd.	4	4	1
Azusa Ave.	5	5	2
Soto St.	3	3	1
Hacienda Blvd.	1	1	1
<b>Totals</b>	<b>139</b>	<b>139</b>	<b>48</b>

size. The other flow direction, i. e., the other side of the road, will then also have a cable of the same size.

- (1) List the total number of freeway and arterial detectors, ND
- (2) List the number of field communications units, NCU
- (3) Calculate the required data rate, DR, as follows:\*

$$DR = \frac{ND \times NB_D + NCU \times NB_A}{PP} \times 1.25 \text{ (in bits/seconds)} \quad (10)$$

-----  
 \*The computation assumes separate wire pairs for each direction of transmission

where

- $NB_D$  = serial message length (number of bits) required for detector data transmission
- $NB_A$  = serial message length (number of bits) required for cabinet address and check bits
- PP = polling period, in seconds
- 1.25 = an adjustment factor for accommodating all other equipment requirements.

(Typical values for  $NB_D$ ,  $NB_A$ , and PP are 30 bits, 30 bits and 30 seconds, respectively, for the local processing, TDM polling approach.)

- (4) Calculate the minimum number of cable pairs required for data handling  $NP_D$ , as follows:

$$NP_D = \frac{DR}{RPP} \quad (11)$$

where RPP is the assigned rate per pair. A conservative estimate for RPP is 600 bits/sec.

- (5) Calculate the minimum number of pairs  $NP_L$ , required to avoid excessive line loading, as follows:

$$NP_L = NCU/20 \quad (12)$$

- (6) Select either  $NP_D$ , or  $NP_L$ , whichever is greater.

- (7) Add additional cable pairs, as follows:

- 5 pairs for direct connection of equipment field cabinets to the "telemetry" cabinets (i. e., field cabinets which also contain communications units).
  - 1 pair for each highway advisory radio (HAR) site
  - 1 pair for each 20 motorist aid phones (none for the present study)
- (8) Sum the number of pairs obtained in steps 6 and 7. Add at least 20 percent for spares (minimum of 2 pairs), and the resulting total will determine the pairs required.

- (9) Select a "standard" cable size, i. e. , the smallest one which provides at least the number of pairs required. For example, if 22 pairs were required, select at least a 25 pair cable; if 42 pairs were required, select at least a 50 pair cable, etc. Typically, standard cables are available with the following numbers of pairs: 6, 12, 18, 25, 37, 50, 75, 100, 150, etc.

The results of applying the above procedure for the freeways and arterials are shown, respectively, in Tables 27 and 28. Table 29 summarizes the cable requirements. For the freeway case, this table includes both flow directions so that the total length of cable (for cost estimating purposes) is determined.

#### I. Control Center

For Candidate A1, the control center is assumed to operate 24 hours per day, 7 days per week. In addition, the dual computer configuration is assumed.

### 13.3 CANDIDATE A2

This candidate uses the same roadway network as candidate A1, but reduces the equipment density to a minimum level. Changes to the subsystems are discussed below.

#### A. Variable Message Signs

As shown previously in Figure 17, 32 VMS locations are deleted for this candidate. Of these, 21 are replaced with HAR installations. The locations not replaced represents cases where either HAR locations already existed in the vicinity, or where diversion points were of low priority.

#### B. Fixed Signing

Since the roadway configuration does not change for this candidate the fixed signing is kept the same as for the previous candidate.

#### C. Highway Advisory Radio

As noted above, 21 HAR installations are added to replace variable message signs. Including the original 15 HAR locations, the total number for this candidate is 36.

#### D. Entrance Ramp Control

Because of the effectiveness of ramp metering, the Handbook contains a guideline to retain all metered ramps in the alternative system designs. The only exception is, of course, the situation where a freeway or freeway section is deleted from the network. This is not the present case, so the number of metered ramps is maintained the same as for candidate A1.

Table 27. Cable Pairs Required for Freeways

Road	(ND) No. Detectors	(NCU) No. Comm Units	DR (BPS)	NP <sub>D</sub> *	NP <sub>L</sub> *	Interconn	HAR	Spares	Total	Standard Cable Selected
I-10	358	41	499	1	2	5	7	2	16	18
Cal 60	330	39	461	1	2	5	4	2	13	18
Cal 57	35	4	49	1	1	5	0	2	8	12
I-210	364	43	509	1	2	5	4	2	13	18
Cal 30	22	2	30	1	1	5	0	2	8	12
I-605	99	13	140	1	1	5	0	2	8	12
Cal 7	30	4	43	1	1	5	0	2	8	12
Cal 2	41	5	58	1	1	5	0	2	8	12
I-5	61	10	89	1	1	5	0	2	8	12

-----

\*Use NP<sub>L</sub> or NP<sub>D</sub>, whichever is greater

Table 28. Cable Pairs Required for Arterials

Road	No. Detectors	No. Comm. Units	DR	NP <sub>D</sub> *	NP <sub>L</sub> *	Interconn	Spares	Total	Standard Cable Selected
Valley Blvd.	198	13	264	1	1	5	2	8	12
Garvey Ave.	66	4	88	1	1	5	2	8	12
Mission Rd.	12	1	16	1	1	5	2	8	12
Huntington Dr.	128	7	169	1	1	5	2	8	12
Las Tunas, etc.	126	9	169	1	1	5	2	8	12
Colorado Blvd.	50	4	68	1	1	5	2	8	12
Foothill Blvd.	56	4	75	1	1	5	2	8	12
Atlantic Blvd.	4	1	6	1	1	5	2	8	12
Rosemead Blvd.	32	1	41	1	1	5	2	8	12
Azusa Ave.	32	2	43	1	1	5	2	8	12
Soto St.	12	1	16	1	1	5	2	8	12
Hacienda Blvd.	8	1	11	1	1	5	2	8	12

-----  
 \*Use NP<sub>L</sub> or NP<sub>D</sub>, whichever is greater. In this case use either since they are equal.

Table 29. Cable Requirements Summary

1. Freeways

Road	Length		Cable Size (Prs.)
	Dir. Miles	Dir. K Ft.	
I-10	53.2	281	18
Cal 60	50.4	266	18
Cal 57	6.4	34	12
I-210	58.8	310	18
Cal 30	5.4	29	12
I-605	16.8	89	12
Cal 7	6.4	34	12
Cal 2	7.2	38	12
I-5	8.2	43	12

**Freeway Summary:**

857 K Ft of 18-pair  
267 K Ft of 12-pair

---

**1,124 K Ft of Cable**

2. Arterials

Road	Length		Cable Size (Prs.)
	Miles	K Ft.	
Valley	28.6	151	12
Garvey	8.8	46	12
Mission	2.6	14	12
Huntington	15.2	80	12
Las Tunas, etc.	21.0	111	12
Colorado	7.9	42	12
Foothill	10.0	53	12
Atlantic	0.6	3	12
Rosemead	2.8	15	12
Azusa	4.1	22	12
Soto	2.4	13	12
Hacienda	1.0	5	12

**Arterial Summary:**

555 K Ft of 12-pair

NOTE: 1 Mile = 1.61 Km, 1K FT = .305 Km

#### E. Freeway Surveillance

For this candidate, the detector spacing on the mainline is increased to 1 mile (1.6 km). Ramp surveillance is maintained as before.

#### F. Arterial Surveillance

Arterial surveillance is not reduced when the same roadway network is considered, nor is the number of critical intersections.

#### G. Pre-trip/Enroute Information Services

These services are deleted in candidate A2.

#### H. Communications

The increased detector spacing on the freeways results in the need for fewer cabinets and thus fewer communications units. Half of the freeway cabinets ( $426/2 = 213$ ) are deleted; thus 71 of the communications units are also deleted. As noted in the Handbook, the cable size is retained for future growth capability.

#### I. Control Center

In this candidate, half-time operation (12 hours) is assumed. Also the dual computer configuration is changed to a single computer.

### 13.4 CANDIDATES B1 AND B2

The roadway network for these candidates was shown in Figure 11. Candidate B1 represents the full equipment complement for this network while B2 is the minimum equipment complement. The subsystem elements are discussed below.

#### A. Variable Message Signs and Highway Advisory Radio

The VMS and HAR locations for these candidates are shown in Figure 18. For candidate B1, 14 VMS locations are eliminated due to the portions of the network excluded. For candidate B2, an additional 20 VMS locations are deleted, 15 of which are replaced by HAR installations.

#### B. Fixed Signing

The route guidance/route confirmation signing is located on arterials, and since some arterials are excluded in these candidates (about 31 percent of the total arterial length), a proportionate reduction in cost over the "A" network is assumed. The system identification signing is retained as before.



### C. Entrance Ramp Control

For these candidates, the ramp metering on I-5, Cal 2, and most of I-210 is deleted, consistent with the deleted roadway portions. A total of 27 metered ramps are excluded, with the following breakdown:

I-5	9
Cal 2	1
I-210	17 (retained only the portion between Huntington Dr. & I-605)
	<hr/>
	27

### D. Freeway and Arterial Surveillance

Freeway surveillance requirements for candidate A1 (the largest system) were presented in Table 23. The requirements for candidate B1 are the same, except for the roadways deleted. Thus for B1, the requirements on Cal 2 and I-5 are deleted, as are 45 percent of those on I-210 (the amount of I-210 deleted). The requirements for candidate B2, which has 1 mile (1.6 km) detector spacing on the mainline, is then one-half of the B1 mainline requirements.

For both candidates B1 and B2, the arterial surveillance is determined from Table 24, by removing the deleted arterials (Azusa, Colorado, Las Tunas/Live Oak/Arrow). These roadways represent approximately 31 percent of the total arterial length, thus the arterial surveillance requirements for the 2 candidates are 69 percent of "A" candidates.

Because of the arterials deleted, the number of critical intersections reduces from 13 to 9 for these candidates. Also, the number of non-CIC intersections reduces from 126 to 86.

### E. Communications

Cabinet requirements for candidate B1 may be determined on a mileage basis relative to candidate A1. B1 retains 80.4 percent of the freeway length and 68.6 percent of the arterial length. These percentages are applied to the A1 case to give the following quantities:

Freeway Cabinets	765
Arterial Cabinets	95
	<hr/>
Total	860

For Candidate B2, there are fewer freeway cabinets due to the increased detector spacing. The number may be calculated as follows: of the 765 cabinets in B1, 45 percent are mainline cabinets. (This percentage is established from Table 25. The other freeway cabinets are for ramps.) Thus there are 344 mainline cabinets, half of which are now excluded due to increased detector spacing. Candidate B2 therefore has 172 less cabinets than B1, or a total of 688 cabinets.

The number of communications units for these candidates are then one-third of the number of cabinets. Also, cable lengths are reduced in proportion to the length of roadways deleted.

#### F. Pre-Trip/Enroute Information Services

These services are included in candidate B1 and excluded in candidate B2, similar to what was done for the "A" candidates.

#### G. Control Center

The same policy is applied as for the "A" candidates, thus B1 has full-time operation and a dual computer configuration while B2 has half-time operation and a single computer configuration.

### 13.5 CANDIDATES C1, C2, D1, AND D2

The development of these alternative design candidates follows the same procedures as described in the previous paragraphs for the A and B candidates. The roadway networks for the C and D candidates were shown, respectively, in Figures 12 and 13. The locations of variable message signs and highway advisory radio installations for these candidates are shown in Figures 19 and 20.

The results of the design development for the C and D candidates are included in the System Design Summary shown in Table 30.



CANDIDATE D1 CONTAINS ALL EQUIPMENT SHOWN  
 \*DENOTES VMS REPLACED WITH HAR IN CANDIDATE D2  
 \*\*DENOTES VMS DELETED IN CANDIDATE D2

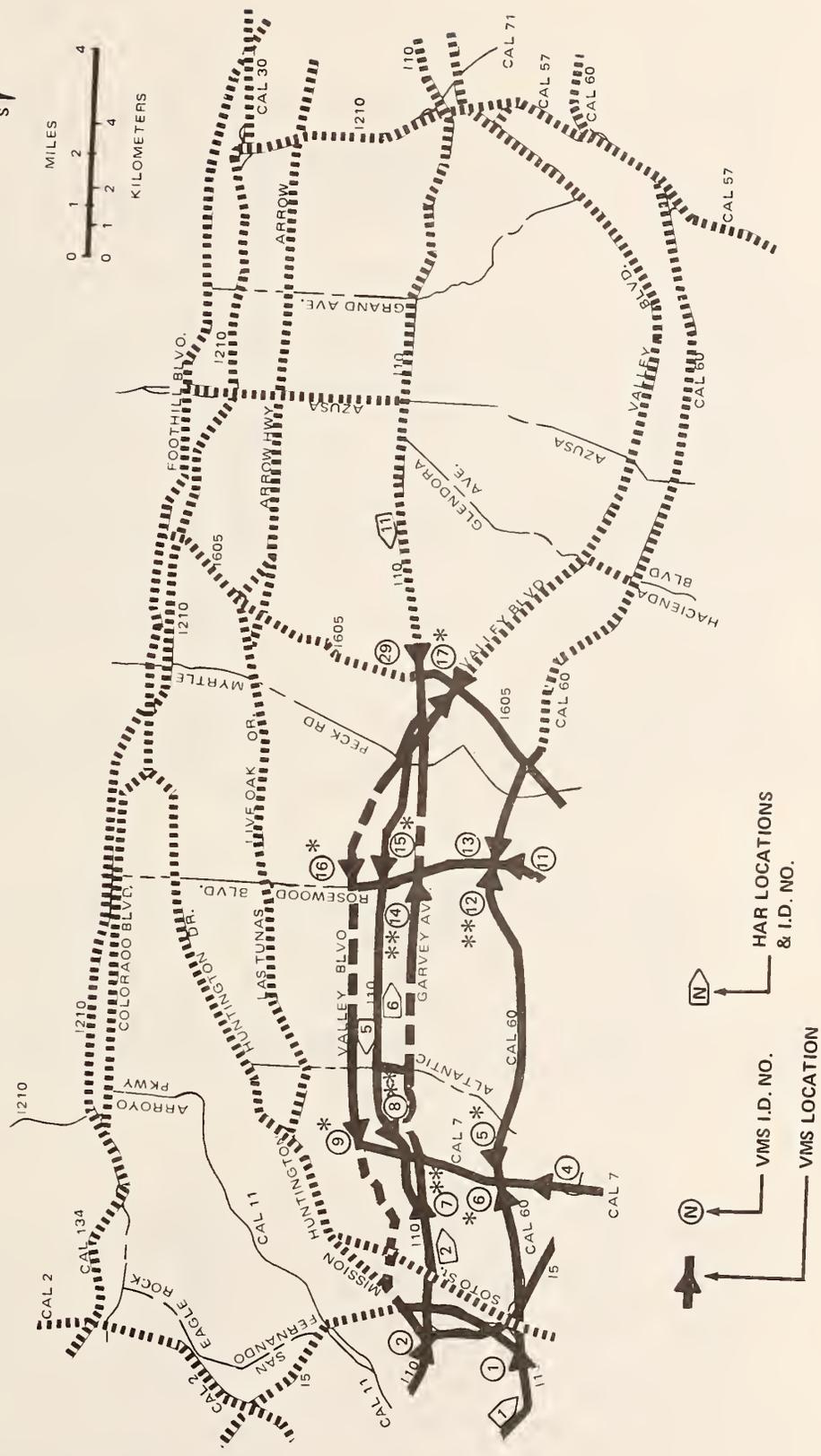


Figure 20. Variable Message Sign and Highway Advisory Radio Locations for Candidates D1 and D2

Table 30. System Design Summary

Subsystem	Equipment Complement	Candidate Designs							
		Network A		Network B		Network C		Network D	
		A1	A2	B1	B2	C1	C2	D1	D2
Diversion/Motorist Advisory	Visual Sign Loc. (#) Hwy Adv Radio Loc. (#)	49 15	17 36	35 12	15 27	27 10	10 22	16 7	6 13
Ramp Metering	Metering Stations (#)	97	97	70	70	64	64	64	64
Arterial Control	CIC Intersection (#) Non-CIC Int. (#)	13 126	13 126	9 86	9 86	7 51	7 51	6 33	6 33
Surveillance	Freeway Det. Spacing (Miles) Arterial Det. Sta. (#) (Non-CIC)	1/2 252	1 252	1/2 172	1 172	1/2 102	1 102	1/2 66	1 66
Communications	Cabinet Loc. (#)	1,091	878	860	688	606	485	329	265
Control Center	Computers (#) Coverage (%)	2 100	1 50	2 100	1 50	2 100	1 50	2 100	1 50
Motorist Aid	Stations (#)	Existing							
Pre-Trip Information Serv.	Inclusion	YES	NO	YES	NO	YES	NO	YES	NO
Incident Management	Police Cars (#) Tow Trucks (#)	Existing							

Note: 1 mile = 1.61 Km.

## SECTION 14

### DETERMINATION OF SYSTEM COSTS

#### 14.1 INTRODUCTION

In this section, costs are developed for each of the eight candidate system designs. Initially, the capital costs, annual maintenance costs, and annual operating costs are developed on a subsystem basis. The non-recurring costs associated with system implementation (maintenance of traffic, mobilization, final design, PS&E, and Engineering Services) are added to the subsystem capital costs to provide the total capital (non-recurring) cost. In order to provide a basis for combining the non-recurring cost with the recurring costs, the former is converted to an equivalent annual cost, based on an assumed life cycle (15 years) and interest rate (10 percent). Finally, the equivalent annual capital cost is combined with the annual recurring cost (maintenance and operating) to produce a total system cost (equivalent annual). This value is used later with the annual benefits to compute benefit/cost ratios.

The basis for the cost determination is the unit cost and equipment quantity data developed in the previous two sections. It is again convenient to deal with the largest system first (candidate A1). Then, costs for the other candidates may be determined by subtracting the deleted roadway and equipment costs.

#### 14.2 COSTS FOR CANDIDATE A1

As noted previously, costs are developed on a subsystem basis. Each of the subsystem costs for this candidate are discussed below.

##### 14.2.1 Variable Message Signs

This candidate contains 49 VMS locations, containing 5 different configurations. Based on the unit cost data presented in Section 12, the subsystem costs are calculated as follows:

##### A. Capital:

Config A*	14 @ \$117.4K	+ 15 @ \$163.8K	=	\$4,101K
B	2 @ \$174.5K		=	349K
C*	1 @ \$131K	+ 1 @ \$177K	=	308K
D	1 @ \$210.5K		=	211K
E	15 @ \$51K		=	765K
	Total Capital		=	<u>\$5,734K</u>

-----  
\*For these configurations, half require 1 new sign bridge and half require 2 new sign bridges. Thus, the two prices are used.

B. Maintenance:

Config A	29 @ \$2.13K	=	\$61.77K
B	2 @ \$2.48K	=	\$ 4.96K
C	2 @ \$2.55K	=	\$ 5.10K
D	1 @ \$2.90K	=	\$ 2.90K
E	15 @ \$0.99K	=	\$14.85K
	Total Maint	=	\$89.58K
	(round off to 90K)		

C. Operating:

Config A	29 @ \$ .841K	=	\$24.4K
B	2 @ \$1.051K	=	2.1K
C	2 @ \$ .841K	=	1.7K
D	1 @ \$1.051K	=	1.1K
E	15 @ \$ .280K	=	4.2K
	Total Ops	=	\$33.5K
	(round off to 34K)		

14.2.2 Fixed Signing

For the route guidance/route confirmation signs, the "lump sum" estimate of \$500 per corridor mile (\$311 per corridor km) was used. The corridor is approximately 26 miles (42 km) long; thus the cost is estimated at \$13,000.

There are 12 system identification signs. Using a unit cost of \$1,000 per sign, the cost for this type of signing is \$12,000.

The total system cost for fixed signs is the sum of the above two types, or \$25,000.

14.2.3 Highway Advisory Radio

This candidate contains 15 highway advisory radio locations. The unit costs and system costs are shown below:

	<u>Unit Costs</u>	<u>System Costs (15 units)</u>
Capital	\$20 K	\$300 K
Maintenance	\$ 2.5K	\$ 37.5K (round off to 38K)
Operating	\$ .2K	\$ 3 K

14.2.4 Entrance Ramp Control

There are 97 metered ramps in this candidate. The unit costs and system costs are shown below.

<u>Unit Costs</u>		<u>System Costs (97 Units)</u>	
Capital	\$14,050		\$1,363K
Maintenance	\$ 400		\$ 39K
Operating	\$ 120		\$ 12K

#### 14.2.5 Freeway Surveillance

Unit costs for freeway surveillance are on a per-lane basis for the mainline and per-ramp basis for non-metered ramps. Because of the varied lane configurations on the freeways, each roadway and lane configuration was treated separately in the cost determination. Table 31 summarized the computation of the freeway surveillance costs. The form of the table is such that it allows costs for other configurations to be estimated rapidly as roadways are removed or detector spacing is changed.

#### 14.2.6 Arterial Surveillance and Control

This candidate contains 252 non-CIC detector stations and 13 CIC intersections. The total number of intersections is 139. Based on the unit cost data in Section 12, costs for this candidate are as follows.

##### A. Surveillance

Capital	252 x \$2500 + 13 x \$27,500	=	\$988K
Maint	252 x \$ 100 + 13 x \$ 400	=	\$ 30K
Ops	252 x \$ 20 + 13 x \$ 90	=	\$ 6K

##### B. Control

Capital	139 x \$500	=	\$ 70K
Maint	139 x \$ 50	=	\$ 7K
Ops	(negl)	=	(negl.)

##### C. Total

Capital	= \$1,058K
Maint	= \$ 37K
Ops	= \$ 6K

#### 14.2.7 Communications

The first part of the communications cost estimate deals with the cable costs. Table 32 shows this calculation. The assumptions used in completing the table are noted below:

- Percent earth border
  - I-10 - 65 percent
  - I-210 - 75 percent
  - All other fwys - 95 percent
- Composite avg. on a mileage basis = 82 percent earth (therefore 18 percent hard)

Table 31. Freeway Surveillance Costs

Road	Number of Stations			Total No. of Detector Lanes	Added Trap Lanes	Capital Cost (K\$)		Total Cap Cost (K\$)	Maint Total Maint (K\$)	Ops Total Ops (K\$)	(For Ops. Costs) Total No. Fwy Mainline And Unmetered Ramp Detectors
	3-Lane	4-Lane	5-Lane			6-Lane	Mainline Cost (K\$)				
I-10	-	76	18	13	40	504	119	623	25	4.3	620
Cal 60	-	82	11	8	40	463	111	574	23	4.0	572
Cal 57	-	13	-	-	8	58	11	69	3	0.5	70
I-210	-	92	26	-	48	536	131	667	27	4.7	665
Cal 30	-	11	-	-	0	44	0	44	2	0.3	44
I-605	-	34	-	-	16	149	41	190	8	1.3	189
Cal 7	13	-	-	-	6	44	9	53	2	0.4	53
Cal 2	-	14	-	-	8	62	17	79	3	0.6	79
I-5	8	8	-	-	7	62	34	96	4	0.7	94
						1,922	473	2,395	97	16.8	2,386
										(use 17K)	

Mainline Capital Cost = 1K/lane + .8K/lane/trap; Ramp Capital Cost = \$1.1K/ramp.

Annual Maint. Cost = \$40/lane (\$40/detector)

Annual Op. Cost per detector (assume 10 watts and .08/kwhr):

$$\text{Cost} = \frac{8760 \text{ hrs} \times .01 \text{ Kw} \times \$0.08}{\text{yr}} = \$7/\text{yr/detector}$$

Kwhr

Table 32. Cable Cost Estimate Worksheet

ID	Cost Factors	Unit	Qty	Cost (M\$)
A	Freeway earth border length	Kft.	920	
B	Cable plowing and splicing cost A x B x 1000	\$/Ft	3	2.760
C	Freeway hard or steep border length	Kft	200	
D	Trenching or mounting conduit C x D x 1000	\$/ft	20	4.000
E	No. of bridges	No.	140	
F	Avg. distance along fwy	Ft.	120	
G	Installed conduit cost E x F x G	\$/ft.	30	0.504
H	No. of ramps	No.	526	
I	Avg. width of ramp	Ft.	30	
J	Jacking or trenching cost H x I x J	\$/ft	25	0.395
K	Length of cable	Kft	1124	
L	Cable cost (weighted avg.) K x L	\$/Kft	276	0.310
M	No. of splice boxes	No.	1000	
N	Cost of splice box (installed) M x N	\$	200	0.200
O	No. of freeway cabinets	No.	952	
P	Avg. distance to main cable	ft.	100	
Q	Plowing/Trenching cost O x P x Q	\$/Ft	10	0.952
R	No. of freeway AC power sources	No.	952	
S	Avg. distance to main cable	ft.	30	
T	Plowing/Trenching cost R x S x T	\$/Ft	10	0.287
U	Avg. AC plow distance/cabinet	ft	100	
V	Incremental cost of common plowing O x U x V	\$/ft	1	0.095
	SUBTOTAL (FREEWAYS)			9.503
AA	Arterial Hard shoulder length	Kft	55	
BB	Trenching/conduit/cable cost AA x BB x 1000	\$/ft	25	1.375
CC	Arterial Soft shoulder length	Kft	492	
DD	Trenching/conduit/cable cost CC x DD x 1000	\$/ft	7	3.444
EE	Existing (or planned) conduit length	Kft	0	
FF	Cable replacement EE x FF x 1000	\$/ft		0
GG	AC Power Cost	\$		.140
	SUBTOTAL (ARTERIALS)			4.819
	TOTAL			14.322

Note: 1 ft = 0.3048 meters,  
\$1/ft = \$3.28/meter

Annual Cable maintenance  
taken as .5% of cable cost  
= \$72K  
(no operating cost for cable)

- Length (Freeways)
  - Total Fwy = 106.4 mi (171.3 km) one direction
  - = 562 K ft (171.3 K meters) one direction
  - = 1124 K ft (342.6 K meters) both directions
  - 82 percent earth = 922 K ft (281 K meters)
  - 18 percent hard = 202 K ft (61.6 K meters)
  
- Bridges
  - Located every 1.5 miles (2.4 km)
  - $\frac{106.4}{1.5} \times 2 = 140$  bridges
  
- Length (Arterials)
  - Total Arterials = 103.6 miles (166.7 km)
  - = 547 K ft (166.7 K meters)
  - 90 percent soft = 492 K ft (150 K meters)
  - 10 percent hard = 55 K ft (16.8 K meters)
  
- Splice boxes
  - # splice boxes = 1.5 (# of ramps + # of bridges)
  - = 1.5 (526 + 140)
  - = 999
  
- Arterial Power
  - Cost = \$1000 per intersection
  
- Wire Cost
  - 12 pair      \$200/K ft (\$656/K meter)
  - 18 pair      \$300/K ft (\$984/K meter)
  - weighted avg for fwys =  $\frac{857 \times \$300 + 267 \times \$200}{1,124}$
  - = \$276/K ft (\$906/K meter)

The second part of the communication subsystem cost is that of the communication units. These costs are outlined below:

A. Capital

Freeways	319	comm units	
Arterials	48	comm units	
Total	367	@ 2K each	= \$734K

B. Maintenance

1 service call per year (@ \$150) per comm. unit  
 $\$150 \times 367 = \$55K$

C. Operating

20 watts per unit  
 $367 \text{ units} \times .02 \text{ KW} \times 8760 \text{ hrs/yr} \times \$.08/\text{Kwh} = \$5K$

The total costs for the communications subsystem is the sum of the cable costs and communication units costs, thus:

Capital	=	\$15,056K
Maintenance	=	127K
Operating	=	5K

#### 14.2.8 Equipment Cabinets

Costs for equipment cabinets are based on the average unit price of \$1,250. There are 952 freeway cabinets and 139 arterial cabinets, for a total of 1,091. The cost is thus:

$$1,091 \times \$1,250 = \$1,364K$$

Annual maintenance is based on 10 cabinet knockdowns per year, at a unit cost of \$1,500. The maintenance cost is therefore:

$$10 \times \$1500 = \$15K/yr$$

Cabinets operating costs are neglected.

#### 14.2.9 Control Center

Cost estimates for the control center are given in the Handbook. These values are used for the present study, and are summarized below.

Capital		550K
Annual Maint @ 12 percent		66K/yr
Annual Operating		
Personnel - 12 @ \$35K burdened*	=	\$420K/yr
Telephone, power, misc.	=	<u>20K/yr</u>
		\$440K/yr

#### 14.2.10 Pre-trip/Enroute Information Services

Based on the unit cost data contained in Section 12, and assuming that there are 4 participating radio stations, the total subsystem costs are as follows:

Capital	\$72K
Maintenance	5K
Operating	26K

#### 14.2.11 Summary for Candidate A1

The costs for this candidate are summarized in Table 33. As noted earlier, the costs are subsequently put into the form of an equivalent annual system cost.

-----

\*This cost was assumed for the present study.

Table 33. System Cost Summary, Candidate A1

Cost Factor	System Cost		
	Capital (M\$)	Annual Maintenance (K\$)	Annual Operation (K\$)
<b>A. Subsystem</b>			
1. Variable Message Signs	5.734	90	34
2. Highway Advisory Radio	.300	38	3
3. Ramp Metering	1.363	39	12
4. Freeway Surveillance	2.395	97	17
5. Arterial Surveillance	1.058	37	6
6. Communications	15.056	127	5
7. Equipment Cabinets	1.364	15	negl.
8. Control Center	.550	66	440
9. Motorist Aid	--	--	--
10. Pre-Trip Information	.072	5	26
11. Miscellaneous*	.025	--	--
<b>B. TOTAL - ALL SUBSYSTEMS CAPITAL</b>	<b>27.917</b>		
<b>C. MAINTENANCE OF TRAFFIC</b>			
C = (.05) (B)	1.396		
<b>D. MOBILIZATION</b>			
D = (.03) (B + C)	.879		
<b>E. FINAL DESIGN, PS&amp;E, ENGINEERING SERVICES</b>			
E = (.15) (B)	4.188		
<b>F. NONRECURRING TOTAL</b>			
F = B + C + D + E	34.380		
F' = Equiv. Annual Value of F	4.520		
<b>G. RECURRING TOTAL</b>		514 (.514M)	
1. Maintenance			
2. Operation			543 (.543M)
<b>H. SYSTEM TOTAL (EQUIV. ANNUAL)</b>			
H = F' + G1 + G2	\$5.577M		

\*Includes fixed message signs

### 14.3 COSTS FOR OTHER CANDIDATE SYSTEMS

Following the procedures used for candidate A1, the costs for the other seven candidates were developed and are summarized in Tables 34 through 40.

### 14.4 COST SUMMARY

System costs for all 8 candidates are presented in summary form in Table 41.

For the purposes of this study, it is assumed that there is no cost constraint and thus no systems are excluded on this basis. If a cost constraint should exist and one or more systems exceed the constraint, they could be dropped at this point if desired. However, the additional effort to retain them is small and it is suggested that they be kept to provide a broader base for comparison of the alternative designs.

Table 34. System Cost Summary, Candidate A2

Cost Factor	System Cost		
	Capital (M\$)	Annual Maintenance (K\$)	Annual Operation (K\$)
<b>A. Subsystem</b>			
1. Variable Message Signs	2.385	37	14
2. Highway Advisory Radio	.720	91	7
3. Ramp Metering	1.363	39	12
4. Freeway Surveillance	1.434	58	10
5. Arterial Surveillance	1.058	37	6
6. Communications	14.616	114	4
7. Equipment Cabinets	1.098	12	negl.
8. Control Center	.310	37	290
9. Motorist Aid	--	--	--
10. Pre-Trip Information	--	--	--
11. Miscellaneous*	.025	--	--
<b>B. TOTAL - ALL SUBSYSTEMS CAPITAL</b>	<b>23.009</b>		
<b>C. MAINTENANCE OF TRAFFIC</b> C = (.05) (B)	<b>1.150</b>		
<b>D. MOBILIZATION</b> D = (.03) (B + C)	<b>.725</b>		
<b>E. FINAL DESIGN, PS&amp;E ENGINEERING SERVICES</b> E = (.15) (B)	<b>3.451</b>		
<b>F. NONRECURRING TOTAL</b> F = B + C + D + E F' = Equiv. Annual Value of F	<b>28.335</b> <b>3.725</b>		
<b>G. RECURRING TOTAL</b>		<b>425 (.425M)</b>	
1. Maintenance			
2. Operation			<b>343 (.343M)</b>
<b>H. SYSTEM TOTAL (EQUIV. ANNUAL)</b> H = F' + G1 + G2	<b>\$4.493M</b>		

\*Includes fixed message signs

Table 35. System Cost Summary, Candidate B1

Cost Factor	System Cost		
	Capital (M\$)	Annual Maintenance (K\$)	Annual Operation (K\$)
<b>A. Subsystem</b>			
1. Variable Message Signs	4.214	66	25
2. Highway Advisory Radio	0.240	30	2
3. Ramp Metering	0.984	28	9
4. Freeway Surveillance	1.920	78	14
5. Arterial Surveillance	0.726	25	4
6. Communications	11.525	98	4
7. Equipment Cabinets	1.095	12	negl.
8. Control Center	.550	66	440
9. Motorist Aid	--	--	--
10. Pre-Trip Information	.072	5	26
11. Miscellaneous*	.021	--	--
<b>B. TOTAL - ALL SUBSYSTEMS CAPITAL</b>	<b>21.327</b>		
<b>C. MAINTENANCE OF TRAFFIC</b> C = (.05) (B)	<b>1.066</b>		
<b>D. MOBILIZATION</b> D = (.03) (B + C)	<b>.672</b>		
<b>E. FINAL DESIGN, PS&amp;E ENGINEERING SERVICES</b> E = (.15) (B)	<b>3.199</b>		
<b>F. NONRECURRING TOTAL</b> F = B + C + D + E F' = Equiv. Annual Value of F	<b>26.264</b> <b>3.453</b>		
<b>G. RECURRING TOTAL</b>			
1. Maintenance		408 (.408M)	
2. Operation			524 (.524M)
<b>H. SYSTEM TOTAL (EQUIV. ANNUAL)</b> H = F' + G1 + G2	<b>\$4.385M</b>		

\*Includes fixed message signs

Table 36. System Cost Summary, Candidate B2

Cost Factor	System Cost		
	Capital (M\$)	Annual Maintenance (K\$)	Annual Operation (K\$)
<b>A. Subsystem</b>			
1. Variable Message Signs	2.105	32	13
2. Highway Advisory Radio	0.540	68	5
3. Ramp Metering	0.984	28	9
4. Freeway Surveillance	1.143	45	8
5. Arterial Surveillance	0.726	25	4
6. Communications	11.170	88	3
7. Equipment Cabinets	0.860	9	negl.
8. Control Center	0.310	37	290
9. Motorist Aid	--	--	--
10. Pre-Trip Information	--	--	--
11. Miscellaneous*	0.21	--	--
<b>B. TOTAL - ALL SUBSYSTEMS CAPITAL</b>	18.048		
<b>C. MAINTENANCE OF TRAFFIC</b> C = (.05) (B)	0.902		
<b>D. MOBILIZATION</b> D = (.03) (B + C)	0.569		
<b>E. FINAL DESIGN, PS&amp;E ENGINEERING SERVICES</b> E = (.15) (B)	2.707		
<b>F. NONRECURRING TOTAL</b> F = B + C + D + E F' = Equiv. Annual Value of F	22.226 2.922		
<b>G. RECURRING TOTAL</b>		332 (.332M)	
1. Maintenance			
2. Operation			332 (.332M)
<b>H. SYSTEM TOTAL (EQUIV. ANNUAL)</b> H = F' + G1 + G2	\$3.586M		

\*Includes fixed message signs

Table 37. System Cost Summary, Candidate C1

Cost Factor	System Cost		
	Capital (M\$)	Annual Maintenance (K\$)	Annual Operation (K\$)
<b>A. Subsystem</b>			
1. Variable Message Signs	3.358	52	20
2. Highway Advisory Radio	0.200	25	2
3. Ramp Metering	0.899	26	8
4. Freeway Surveillance	1.382	56	10
5. Arterial Surveillance	0.477	16	3
6. Communications	7.829	68	3
7. Equipment Cabinets	0.758	9	negl.
8. Control Center	0.550	66	440
9. Motorist Aid	--	--	--
10. Pre-Trip Information	0.072	5	20
11. Miscellaneous*	0.013	--	--
<b>B. TOTAL - ALL SUBSYSTEMS CAPITAL</b>	15.538		
<b>C. MAINTENANCE OF TRAFFIC</b> C = (.05) (B)	0.777		
<b>D. MOBILIZATION</b> D = (.03) (B + C)	0.489		
<b>E. FINAL DESIGN, PS&amp;E ENGINEERING SERVICES</b> E = (.15) (B)	2.331		
<b>F. NONRECURRING TOTAL</b> F = B + C + D + E F' = Equiv. Annual Value of F	19.135 2.516		
<b>G. RECURRING TOTAL</b>			
1. Maintenance		323 (.323M)	
2. Operation			506 (.506M)
<b>H. SYSTEM TOTAL (EQUIV. ANNUAL)</b> H = F' + G1 + G2	\$3.345M		

\*Includes fixed message signs

Table 38. System Cost Summary, Candidate C2

Cost Factor	System Cost		
	Capital (M\$)	Annual Maintenance (K\$)	Annual Operation (K\$)
<b>A. Subsystem</b>			
1. Variable Message Signs	1.491	23	9
2. Highway Advisory Radio	.460	58	4
3. Ramp Metering	0.899	26	8
4. Freeway Surveillance	0.828	32	6
5. Arterial Surveillance	0.477	16	3
6. Communications	7.576	61	2
7. Equipment Cabinets	.606	8	negl.
8. Control Center	.310	37	290
9. Motorist Aid	--	--	--
10. Pre-Trip Information	--	--	--
11. Miscellaneous*	.013	--	--
<b>B. TOTAL - ALL SUBSYSTEMS CAPITAL</b>	<b>12.660</b>		
<b>C. MAINTENANCE OF TRAFFIC</b>	<b>.633</b>		
C = (.05) (B)			
<b>D. MOBILIZATION</b>			
D = (.03) (B + C)	<b>.399</b>		
<b>E. FINAL DESIGN, PS&amp;E, ENGINEERING SERVICES</b>	<b>1.899</b>		
E = (.15) (B)			
<b>F. NONRECURRING TOTAL</b>			
F = B + C + D + E	<b>15.591</b>		
F' = Equiv. Annual Value of F	<b>2.050</b>		
<b>G. RECURRING TOTAL</b>			
1. Maintenance		<b>261 (.261M)</b>	
2. Operation			<b>322 (.322M)</b>
<b>H. SYSTEM TOTAL (EQUIV. ANNUAL)</b>			
H = F' + G1 + G2	<b>\$2.633M</b>		

\*Includes fixed message signs

Table 39. System Cost Summary, Candidate D1

Cost Factor	System Cost		
	Capital (M\$)	Annual Maintenance (K\$)	Annual Operation (K\$)
<b>A. Subsystem</b>			
1. Variable Message Signs	2.056	32	12
2. Highway Advisory Radio	.140	18	1
3. Ramp Metering	.899	26	8
4. Freeway Surveillance	.730	29	5
5. Arterial Surveillance	.350	11	2
6. Communications	4.354	37	2
7. Equipment Cabinets	.411	6	negl.
8. Control Center	.550	66	440
9. Motorist Aid	--	--	--
10. Pre-Trip Information	.072	5	20
11. Miscellaneous*	.011	--	--
<b>B. TOTAL - ALL SUBSYSTEMS CAPITAL</b>	<b>9.573</b>		
<b>C. MAINTENANCE OF TRAFFIC</b>	<b>.479</b>		
C = (.05) (B)			
<b>D. MOBILIZATION</b>	<b>.302</b>		
D = (.03) (B + C)			
<b>E. FINAL DESIGN, PS&amp;E, ENGINEERING SERVICES</b>	<b>1.436</b>		
E = (.15) (B)			
<b>F. NONRECURRING TOTAL</b>			
F = B + C + D + E	<b>11.790</b>		
F' = Equiv. Annual Value of F	<b>1.550</b>		
<b>G. RECURRING TOTAL</b>		<b>230 (.230M)</b>	
1. Maintenance			
2. Operation			<b>490 (.490M)</b>
<b>H. SYSTEM TOTAL (EQUIV. ANNUAL)</b>			
H = F' + G1 + G2	<b>\$2.270M</b>		

\*Includes fixed message signs

Table 40. System Cost Summary, Candidate D2

Cost Factor	System Cost		
	Capital (M\$)	Annual Maintenance (K\$)	Annual Operation (K\$)
<b>A. Subsystem</b>			
1. Variable Message Signs	.815	13	5
2. Highway Advisory Radio	.260	33	3
3. Ramp Metering	.899	26	8
4. Freeway Surveillance	.435	17	3
5. Arterial Surveillance	.350	11	2
6. Communications	4.220	33	1
7. Equipment Cabinets	.331	5	negl.
8. Control Center	.310	37	290
9. Motorist Aid	--	--	--
10. Pre-Trip Information	--	--	--
11. Miscellaneous*	.011	--	--
<b>B. TOTAL - ALL SUBSYSTEMS CAPITAL</b>	<b>7.631</b>		
<b>C. MAINTENANCE OF TRAFFIC</b> C = (.05) (B)	.382		
<b>D. MOBILIZATION</b> D = (.03) (B + C)	.240		
<b>E. FINAL DESIGN, PS&amp;E ENGINEERING SERVICES</b> E = (.15) (B)	1.145		
<b>F. NONRECURRING TOTAL</b> F = B + C + D + E F' = Equiv. Annual Value of F	9.398 1.236		
<b>G. RECURRING TOTAL</b>		175 (.175M)	
1. Maintenance			
2. Operation			312 (.312M)
<b>H. SYSTEM TOTAL (EQUIV. ANNUAL)</b> H = F' + G1 + G2	<b>\$1.723M</b>		

\*Includes fixed message signs

Table 41. Candidate System Cost Summary

Candidate System	System Costs (Millions Of Dollars)				
	Total Capital	Equiv. Annual Capital*	Annual Maint.	Annual Operations	Equiv. Annual Total
A1	34.380	4.520	0.514	0.543	5.577
A2	28.335	3.725	0.425	0.343	4.493
B1	26.264	3.453	0.408	0.524	4.385
B2	22.226	2.922	0.332	0.332	3.586
C1	19.135	2.516	0.323	0.506	3.345
C2	15.591	2.050	0.261	0.322	2.633
D1	11.790	1.550	0.230	0.490	2.270
D2	9.398	1.236	0.175	0.312	1.723

\*Based On 10 Percent Interest Rate, 15-Year Life Cycle

## SECTION 15

### DETERMINATION OF SYSTEM BENEFITS

#### 15.1 INTRODUCTION

In this section the benefits are developed for each of the eight system candidate designs. Four benefit categories are computed: vehicle delay, accident reduction, fuel consumption and pollutant emission. The procedure for the delay benefit computation is to develop a set of fundamental benefit factors referenced to a single lane-mile of each limited access roadway. Factors are obtained for recurrent congestion where peak demands exceed system capacities, and incident congestion during both peak and off-peak travel periods. As a function of the roadway flow characteristics, incident characteristics, and the layout of the control areas, distinct benefit factors are assigned to specific subsections of the corridor. The total delay benefit on a yearly basis is obtained by multiplication of the fundamental factors by specific expansion factors.

The computation of the fuel consumption benefit is obtained by utilizing a directly proportional linear relationship between vehicle delay and excess fuel consumed. A similar relationship is used to relate pollutants to vehicle delay. The proportionality coefficients are .96 gal/veh-hr (3.63 liters/veh-hr) for fuel consumption, 2.1 lb/veh-hr (.95 kg./veh-hr) for carbon monoxide, and .1 lbs/veh-hr (.05 kg/veh-hr) for hydrocarbons. Accident reduction benefits are based on the historical accident rate for the limited access corridor roadways. This rate is reduced on the order of 21 percent due to ramp metering and reductions in flow turbulence\*. Accident reduction contributes to overall benefits in two ways. First there is a direct saving in annual accident costs and second there is reduction in vehicle-hours of delay associated with the accidents that have been eliminated.

#### 15.2 BENEFIT DEVELOPMENT - CANDIDATE A1

As previously noted system benefits are developed on a category basis. Each of the benefit categories for this candidate are discussed below. Prior to computing the benefit categories the control policies must be reviewed and the overall control volume  $\Delta Q_{A1}$  established for the candidate. Based on the system design considerations, ramp metering control is warranted in the half of the corridor west of I605. This represents a significant variation in control philosophy between the western and eastern halves and is reflected in the computation. The overall control volumes shift  $\Delta Q_{A1}$  is similarly developed as a two-value quantity

-----  
\*Based on documented before and after studies of operational surveillance and control system.

referenced to the western or eastern halves of the corridor. In Section 8 average available capacities were defined for each alternate roadway on an overall basis. In Section 10 available capacities (utilizing the control probability model standard deviation) for the limited access roadways were obtained. These individual roadway available capacities are summarized below for each major primary and alternate roadway in the A1 candidate.

<u>i</u>		<u>ΔQi</u>
1.	Between I10 and Cal 60	185
2.	Between I10 and I210	185
3.	Huntington Dr/I210	165
4.	Colorado/Foothill Blvd.	190
5.	Arrow/Las Tunas	60
6.	Valley Blvd. West of I605	110
7.	Valley Blvd. East of I605	145
8.	Garvey Ave.	55

To obtain a system wide control volume shift from these independent individual roadway quantities a square root of sum of squares relationship is used.

$$\overline{\Delta Q}_{A1} = \left[ \sum_i (\Delta Q_i)^2 \right]^{1/2}$$

where the individual entries are selected on the basis of roadway location in the corridor.

For candidate A1 west of I605\*

$$\begin{aligned} \overline{\Delta Q}_{A1} &= \left[ (\Delta Q_1)^2 + (\Delta Q_2)^2 + (\Delta Q_4)^2 + (\Delta Q_6)^2 + (\Delta Q_8)^2 \right]^{1/2} \\ &= 340 \text{ veh/lane/hour} \end{aligned}$$

and east of I605

$$\begin{aligned} \overline{\Delta Q}_{A1} &= \left[ (\Delta Q_1)^2 + (\Delta Q_2)^2 + (\Delta Q_4)^2 + (\Delta Q_5)^2 + (\Delta Q_7)^2 \right]^{1/2} \\ &= 360 \text{ veh/lane/hour} \end{aligned}$$

### 15.2.1 Normal Congestion Benefits for Candidate A1

This candidate has three major limited access roadways - I210, I10 and

-----  
\*Note that for the A1 candidate network Huntington Dr. is in actuality a connector (albeit quite long) and therefore is not included in the computation.

Cal 60. As discussed in Section 7, there is minimal congestion east of I605 (except on Cal 60 just east of I605) and hence no significant congestion benefit was assumed obtainable in this section of the A1 network. For the western half of the network the roadways have the congestion characteristics noted below:

Roadway	Mean Flow Level (VPLPH)	No. Lanes (one way)	Miles of Roadway*	Congestion			
				Duration K1 (MIN)	Speed** Uc (MPH)	Duration K1 (MIN)	Speed** Uc (MPH)
I210	1800	4	11.7	45	35	45	35
I210	1800	5	4.9	45	35	45	35
I10	1800	4	9.6	60	40	60	40
I10	1800	6	2.8	60	29	60	29
Cal 60	1800	4	8.6	30	20	30	20
Cal 60	1800	5	3.0	45	20	45	20

Using the benefit and disbenefit relationships described in the IMIS Feasibility Handbook (Chapter 15) the fundamental benefit levels are 42.3 Veh-hrs for one lane-mile (1.6 lane km) of Cal 60 over one peak hour. For the I210 roadway, the benefit level is 13.2 veh-hrs, and for the I10 roadway, the benefit level is 20.5 Veh-hrs (for the roadway section west of Cal 7) and 8.6 Veh-hrs (roadway section east of Cal 7). Following the computational procedures given in Chapter 15 of the Handbook these benefit levels are expanded to yearly values through multiplication with the appropriate expansion and control probability factors. For the normal congestion benefit category these factors are: peak period duration (K1), number of peak periods per day (value = 2), number of roadway directions considered during a peak period (value = 1), number of days benefits achievable per year (value = 260), and the probability factor to describe the percent of time that the exercise of control will result in an actual benefit (for network A1 this factor is .51). Multiplying these factors together with the lane-miles for each roadway section and summing the individual roadway values, the normal congestion benefit for system candidate A1 is 696,976 veh-hrs of delay saved.

### 15.2.2 Peak Period Incident Congestion Benefits for Candidate A1

The peak period incident benefit addresses the requirement of IMIS to reduce the magnitude, extent, and disruptive consequences of incident-caused congestion. The key steps of the computational procedure are based on the Incident Delay Diagram. Figure 21 presents this diagram. The time evolution of the incident scenario is specified on the abscissa. The ordinate specifies the number of vehicles desiring to utilize the incident roadway (demand curve) and the number that can actually utilize the roadway at the location of the incident (capacity curve). The incident scenario is composed of two distinct time lines corresponding to incident occurrence without and with control. For the scenario with control, the demand curve is

-----  
\*1 mile = 1.61 km

\*\*1 mph = 1.61 kmph

modified by the shift of a fraction of the demand volume to an alternate roadway within the corridor. Referring to the figure, the benefit from IMIS control of a single incident is equivalent to the shaded area between the demand curves.

The analytical equations used to develop the incident benefit are given in Chapter 15 of the Handbook. The specific values of the incident parameters for calculation of the benefit (with definitions) are given for the corridor under consideration:

- Demand/Capacity Flow Levels

- $Q_1 = 1116$  VPLPH - Roadway capacity with incident (1 lane blocked for 4 lane roadway) (62 percent of nominal capacity)
- $Q_2 = 1800$  VPLPH - Peak period demand
- $Q_3 = 1800$  VPLPH - Nominal capacity of roadway (per lane)
- $Q_4 = 1386$  VPLPH - Expected peak-to-off-peak demand level. (Typical value 70 to 80 percent of capacity)
- $Q_5 = 1800 - \overline{\Delta Q}_{A1}$  - Expected demand at incident site with control implemented
  - = 1460 VPLPH - West of I605
  - = 1440 VPLPH - East of I605

- Time Intervals (Relative to Time of Incident Occurrence)

- $T_{D/R} = 35$  min - Expected duration of incidents on roadway
- $T_{C1} = 5$  min - Time lag after incident occurrence until control implemented (5 min equivalent to .5 mi (.8 km) detector spacing)
- $T_{C2} = 40$  min - Termination of control. Typical value equal to  $T_{D/R} + T_{C1}$ .
- $T_{PP} = 45$  min - Expected termination time of peak period given an incident has occurred. Typical value equal to .5 (peak period)

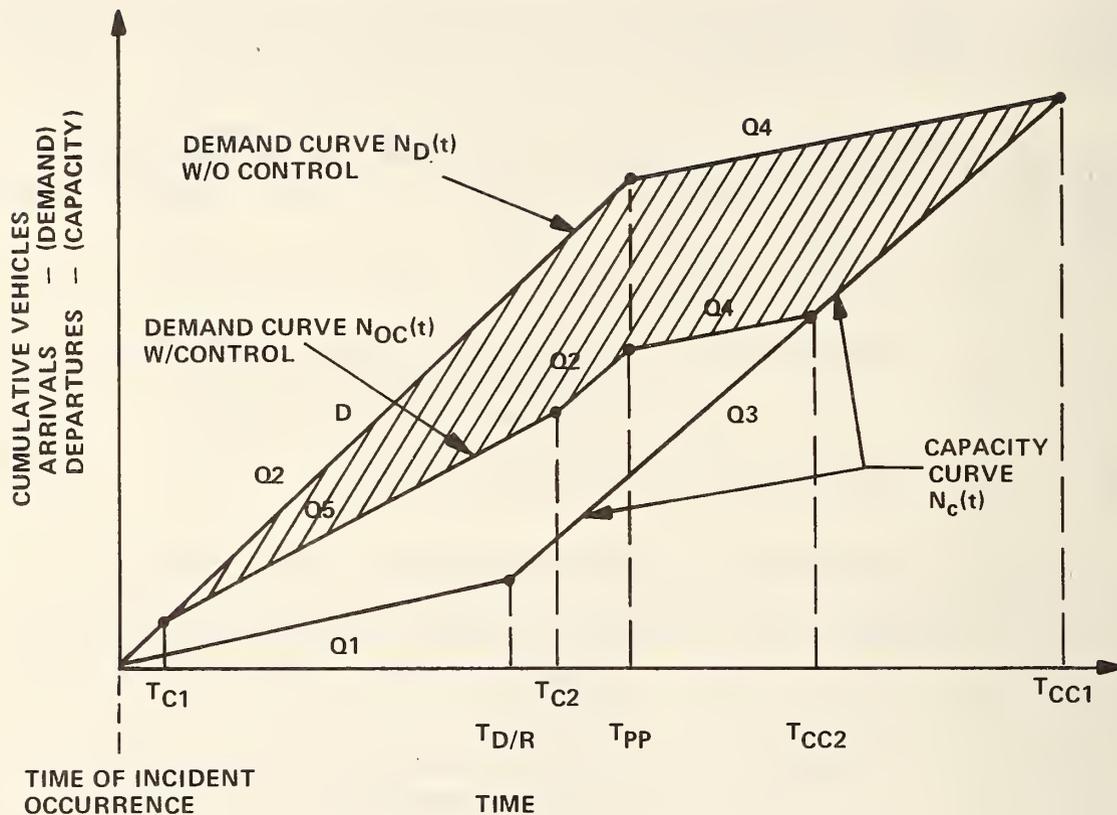


Figure 21. Incident Delay Diagram

$T_{CC1}$	= 102.8 min	Time at which incident caused congestion is eliminated
$T_{CC2}$	= 74.1 min (west)	= no control
	= 72.8 min (east)	= with control
		(calculated parameters per Section 14 of Handbook)

Following the procedures given in the Handbook, the delay saved on a per-lane basis for a single incident is 218 veh-hr for the network west of I605 and 225 veh-hr for the network east of I605. These quantities are based on an incident which blocks one lane of a 4 lane roadway\*. Thus the single incident benefit on a 4 lane roadway is respectively, 872 veh-hr and 900 veh-hr.

-----

\* For incident benefit computations the single direction lane configuration for the major limited access roadways has been set to four, since this is the predominant configuration

The determination of the network-wide incident delay benefit is obtained by multiplying the single incident benefit by the number of lane-blocking incidents (including accidents\*) which occur on the limited access roadways on an annual basis. Incident rates were developed in Section 7 (Supplemental Analyses). The rates were categorized with respect to roadway AADT and peak/off-peak travel periods. This categorization resulted in the rates shown in Table 42 for the test corridor freeways.

Table 42. Freeway Incident Rates

Roadway	Incident Rates**			
	WEST OF I605		EAST OF I605	
	<u>PEAK TRAVEL</u>	<u>OFF-PEAK TRAVEL</u>	<u>PEAK TRAVEL</u>	<u>OFF-PEAK TRAVEL</u>
Cal 60/Cal 57	$2.32 \times 10^{-3}$	$1.5 \times 10^{-3}$	$1.24 \times 10^{-3}$	$6.9 \times 10^{-4}$
I 10	$3. \times 10^{-3}$	$2. \times 10^{-3}$	$1.5 \times 10^{-3}$	$9.5 \times 10^{-4}$
I210/Cal 134	$1.04 \times 10^{-3}$	$3.6 \times 10^{-4}$	$1.04 \times 10^{-3}$	$3.6 \times 10^{-4}$
Connectors:				
I605, between Cal 60 & I 10	Same as Cal 60			
I605, between I10 & I210	Same as I210			
I5, Cal 101, Cal 7	Same as I 10			

\*\*Units are incidents per lane-mile of roadway per hour (1incident per lane-mile = .62 incidents per lane-kilometer)

Multiplication of the number of lane-miles of roadway by the expansion factors and the appropriate incident rates results in the total number of incident occurrences on a yearly basis. There are 790 incidents for the section of the test corridor west of I605 and 344 incidents for the section east of I605 for peak travel periods. Multiplication of incidents by the benefit per incident and the appropriate control probability factor results in a total peak period incident benefit of 569,547 veh-hrs for the test corridor west of I605 and 232, 406 veh-hrs for the test corridor east of I605. The computation of this benefit included a factor for incorporating the "rubbernecking" phenomenon. This factor (50 percent) was applied to those accidents which occur on I 10, Cal 60 and I210 in the direction opposite to the peak travel flow. This factor was not applied to the accidents occurring on the connectors since the connectors would not necessarily have a preferred travel direction.

The control probability factor used for incident benefit computation in the subnetwork east of I605 was modified from the typical factors to account for

\* Typically, accidents represents about half of the lane-blocking incidents

the minimal normal congestion condition existing in that section. Since normal congestion was not indicated, the control probability factor, which quantifies the fraction of control opportunities which result in a beneficial control action, was set to a value of 1.0. This value implies there will almost always be capacity available for the redistribution of traffic in response to incident blockages.

### 15.2.3 OFF-PEAK INCIDENT BENEFIT - CANDIDATE A1

This benefit category addresses the requirement of IMIS to maintain the quality of flow and roadway performance during non-peak time periods. This methodology for obtaining these benefits is similar to the procedures followed in the previous section.

The only differences are principally related to the following factors:

- (1) The roadway demand is substantially below roadway capacity and hence the level of congestion and benefits per incident due to system operation is substantially reduced.
- (2) The probability that control can be exercised after the occurrence of an incident is assumed equal to 1 for all roadway configurations.
- (3) While the volumes are lower, the longer duration of the off-peak time period implies that in general a higher total number of incidents will occur over a year when compared to the number of peak period incidents.

The fundamental benefit levels for the off-peak period can be obtained with the same equation set utilized for peak periods with the substitution of Q4 for Q2. Lowering the demand level, dramatically reduces the level of benefit that can be obtained for a single incident. On a per-incident basis, the fundamental benefit levels (for 4 lane roadways) are 83 veh-hr in the subnetwork east of I605 and 174 veh-hr in the subnetwork west of I605. The difference in the benefit levels is directly related to demand level assigned to each subnetwork based on observed flow conditions. East of I605 the demand level was set to 70 percent of capacity and west of I605 it was set to 75 percent to reflect the differences in off-peak flow levels induced by the variation in the intensity of land use development.

The incident rates for the off-peak period were given in the previous section. Multiplying by the expansion factors and the number of lane-miles for each roadway, the total lane blocking incidents are respectively 1586 incidents west of I605 and 644 incidents east of I605. Multiplying number of incidents by benefit level results in a total vehicle delay benefit of 275,330 veh-hr and 53,323 veh-hr for the subnetworks west and east of I605, respectively.

### 15.2.4 ACCIDENT REDUCTION BENEFIT - CANDIDATE A1

As noted earlier benefit associated with accident reduction is composed of two parts - a reduction in yearly accident costs (fatal, non-fatal and

property damage) and a reduction in the vehicle-hours of delay corresponding to the eliminated accidents. The calculation of this benefit is performed in two parts corresponding to each benefit component. The determination of the number of accidents saved on a yearly basis is found by applying an accident reduction factor to the total number of accidents occurring in the test corridor. The reduction factor is applied only to accidents which occur during peak travel periods when the application of system-wide control policies (including ramp metering) will minimize flow instabilities and provide improved communication to motorists of downstream flow disturbances. Based on evaluations of operational systems a typical reduction factor of 21.5 percent can be used as representative of these reductions. Since for candidate A1 ramp metering and peak period normal congestion occurs only in the subnetwork of the test corridor west of I605, the reduction factor is applied to the total accidents occurring in this subsection. Thus for candidate A1 a reduction of 83 accidents is the benefit level based on a total number of accidents of 395.

The methodology used to calculate the delay savings due to the occurrence of a reduced number of accidents is to multiply the accidents saved (83) by the delay saved per peak period accident. Referring to the Incident Delay Diagram (Figure 21) the total delay saved is recognized as the area between the demand curve without control and the capacity curve. However, since the peak period incident benefit has already taken a benefit based on the historical roadway accident rates, the net additional benefit is the area between the demand curve with control and the capacity curve. Based on the foregoing, the net benefit due to a reduction of one accident from the test corridor historical rate is calculated to be 628 veh-hrs saved.

The total delay benefit attributed to accident reduction is obtained by multiplying this single accident benefit by the number of accidents saved. For candidate A1 this benefit level is 52,157 veh-hrs saved.

#### 15.2.5 FUEL AND POLLUTANT BENEFITS - CANDIDATE A1

In the previous sections the benefit categories of vehicle delay saved and accidents saved were addressed for the A1 system candidate. The computation of the fuel consumption and pollutant emitted benefits are obtained by utilizing linear relationships between vehicle delay and excess fuel and pollutants. As noted earlier, the coefficients of these relationships are .96 for fuel consumption, 2.1 for carbon monoxide, and 0.1 for hydrocarbons. Therefore the levels of benefits for these categories for the A1 candidate are 1,907,081 gallons (7,219,086 liters) of fuel saved, 4,171,740 lbs. (1,892,269 kgs) of carbon monoxide eliminated and 198,654 lbs. (90,108 kgs) of hydrocarbons eliminated.

#### 15.3 BENEFIT DEVELOPMENT - CANDIDATE A2

The development of benefits for system candidate A2 directly follows the procedures defined for system A1. The differences in benefit levels (A2 levels less than A1) are due to the reductions in subsystem equipment complements. Table 30 listed the equipment complements for each candidate design. The design

variations which have a direct impact on benefit levels, for system designs based on the same roadway network, are diversion/motorist advisory signing locations and freeway detector spacing.

Freeway detector spacing has an impact on the level of benefit obtained from the accident and incident benefit categories. As spacing between detectors lengthens the time lag for incident detection and control implementation increases. For candidate A2 the detection lag is 8 minutes, corresponding to a spacing of 1 mile (1.6 km), as opposed to 5 minutes for candidate A1 with its .5 mile (.8 km) spacing.

Reductions in total number of variable message signing locations and/or replacement with highway advisory radio (HAR) has an impact on benefit levels through a reduction in the magnitude of control volumes which can be shifted between roadways. The equation used to compute this reduction is

$$\overline{\Delta Q}_{A2} = R(\overline{\Delta Q}_{A1}) \quad (22)$$

where R is the number in the range 0.0 to 1.0 representing the effectiveness of the reduced sign complement of the A2 candidate with respect to the complete sign complement of the more complete design. The effectiveness, R, is the product of two components: R<sub>1</sub> - a reduction due to loss of sign locations and R<sub>2</sub> - a reduction due to replacement of variable message signing with HAR\*. The Handbook provides the equation for estimating the effectiveness of a reduced sign complement (R<sub>1</sub>). For system A2 (with 53 sign locations) with respect to A1 (with 64 sign locations) the R<sub>1</sub> reduction is .926. The R<sub>2</sub> reduction is .901 based on the fact that 21 of the signs (out of 53) are replaced with HAR. The total reduction in effectiveness is (.926) (.901), or .834. Thus the control volume shift of candidate A2 is 285 VPLH for the subnetwork west of I605 and 300 VPLPH for the subnetwork east of I605.

Incorporating these two modifications:

- (1) 1.0 mile (1.6 km) detector spacing vs 1/2 mile (.8 km) detector spacing
- (2) 53 sign complement vs 64 sign complement

into the methodology procedures results in a reduction of benefit levels for candidate A2. (These levels are given in Table 44.) An overall reduction of 13 percent in vehicle delay benefits was obtained with corresponding reductions in fuel consumption and pollutants emitted benefit levels.

#### 15.4 BENEFIT DEVELOPMENT - REMAINING CANDIDATES

The computation of system benefits for the remaining candidate designs (B1, B2, C1, C2, D1, D2) follows the same procedures given in Sections 15.2 and

-----  
\* Effectiveness of HAR has not yet been quantified. It has presently been assumed that its effectiveness is 75 percent of that of a variable message sign.

15.3. The B1 and B2 candidates are based on the B-network configuration with C1/C2 and D1/D2 designs based on the C and D network configurations. Since the B, C and D networks are subsets of the A network, the level of benefits for the B1, C1, D1 candidate designs will also be reduced in comparison to the A1 benefit levels. The computational procedures used for the '1' designs remain the same. The B2, C2 and D2 candidates in turn have reduced equipment complements and hence the procedures outlined in Section 15.3 are applicable. Table 30 summarized the equipment complements for the set of candidate designs and Figures 18 thru 20 defined the B, C and D networks. Table 43 lists the effectiveness ratings used for the B, C and D design pairs.

Following the procedures given previously the benefit levels for the B, C and D designs have been determined. The results are included in Table 44 which contains the summary for all candidates.

Table 43. Candidate Design Effectiveness Rating\*

Candidate Design Pairs	R1 Reduced Equipment Complement Rating	R2 Less Effective Equipment Rating	R Comparative Rating
A2 - A1	.926	.901	.834
B2 - B1			
East of I605	.964	.906	.873
West of I605	.972	.906	.881
C2 - C1	.942	.909	.856
D2 - D1	.953	.913	.870

\*The effectiveness rating is a relative rating defining the effectiveness of the '2' design with respect to the '1' design where the '1' design is assigned an effectiveness of 1.0.

Table 44. Benefit Summary for the Candidate Systems

BENEFIT CATEGORIES	CANDIDATE SYSTEM							
	A1	A2	B1	B2	C1	C2	D1	D2
A. Delay Saved (VDBY in vehicle-hours/yr)								
(1) Peak Period								
• Normal	755808	711671	533780	509695	484552	415615	469857	404383
• Incident	801953	666595	578738	495645	399121	364954	286099	239811
(2) Off Peak								
• Incident	376625	294106	337223	293977	323615	282413	274626	240783
(3) Accident Reduction	52157	64508	45264	51768	53914	59016	53914	59016
(4) Total	1986543	1736880	1515005	1351085	1261202	1121998	1084496	943993
B. Fuel Saved (FBY, in gallons/yr)	1907081	1667405	1454405	1297042	1210754	1077118	1041116	906233
C. Accident Reduction (ARBY, in No. of accidents/yr)	83	83	60	60	60	60	60	60
D. Pollution Reduction (PBY, in pounds/yr)								
CO	4171740	3647448	3181511	2837279	2648524	2356196	2277442	1982385
HC	198654	173688	151501	135109	126120	112200	108450	94399

NOTE: 1 gallon = 3.8 liters  
1 pound = .45 kilograms

## SECTION 16

### BENEFIT/COST EVALUATION OF ALTERNATIVE SYSTEMS

#### 16.1 INTRODUCTION

In this section, the evaluation of the alternative systems is performed on a benefit/cost basis. The benefits computed in the previous section are first converted to a dollar equivalent and then combined with the cost data (developed in Section 14) to form the basic benefit/cost ratios. Any system having a ratio less than 1.0 is excluded at this point.

The evaluation is carried further by computing incremental benefit/cost ratios, using the lowest cost system as the initial baseline. This type of analysis is useful for assessing the relative worth of additional investments, a factor which should be considered in making a final system selection.

The final portion of this section contains the benefit/cost sensitivity analysis. The purpose of this analysis is to provide an indication of the potential variation in benefit/cost ratio due to uncertainties in the major parameters upon which it is based. This analysis is most important for systems whose benefit/cost ratio is close to 1.0, since in these cases the economic viability of the investment can become subject to question.

#### 16.2 BENEFIT/COST EVALUATION

For the purposes of this evaluation, the quantified benefits in the categories of delay saved, fuel saved, and accident reduction are converted to dollar values. (The reduced pollution benefit is not included since the dollar equivalent cannot be estimated). The following values were used for the conversion:

- Delay saved - \$3.50 per vehicle-hour
- Fuel saved - \$0.65 per gallon (\$0.17 per liter)
- Accidents - \$3,400 per accident (composite value for all types)

The results of the conversion for each candidate system are shown in Table 45, along with the cost data and benefit/cost ratios. The benefit and cost data are also plotted in Figure 22. As can be seen from these results, system D2 has the highest value and is "best" from this point of view. However, all systems have benefit/cost ratios greater than one; thus, they are all retained for the incremental benefit/cost analysis.

For calculation of the incremental benefit/cost ratios, the candidate systems are listed in order of increasing cost, along with their associated cost and benefit data.

Table 45. Benefit/Cost Evaluation

Candidate System	Annual Benefits			Annual Benefit Total (Millions)	Equiv. Annual Cost (Millions)	B/C Ratio
	Delay	Fuel	Accident			
A1	\$ 6,952,900	\$ 1,239,603	\$ 282,200	\$ 8.474	\$ 5.577	1.52
A2	6,079,080	1,083,813	282,200	7.445	4.493	1.66
B1	5,302,517	945,363	204,000	6.451	4.385	1.47
B2	4,728,797	843,077	204,000	5.775	3.586	1.61
C1	4,414,207	786,990	204,000	5.405	3.345	1.62
C2	3,926,993	700,127	204,000	4.831	2.633	1.83
D1	3,795,736	676,725	204,000	4.676	2.270	2.06
D2	3,303,976	589,051	204,000	4.097	1.723	2.38

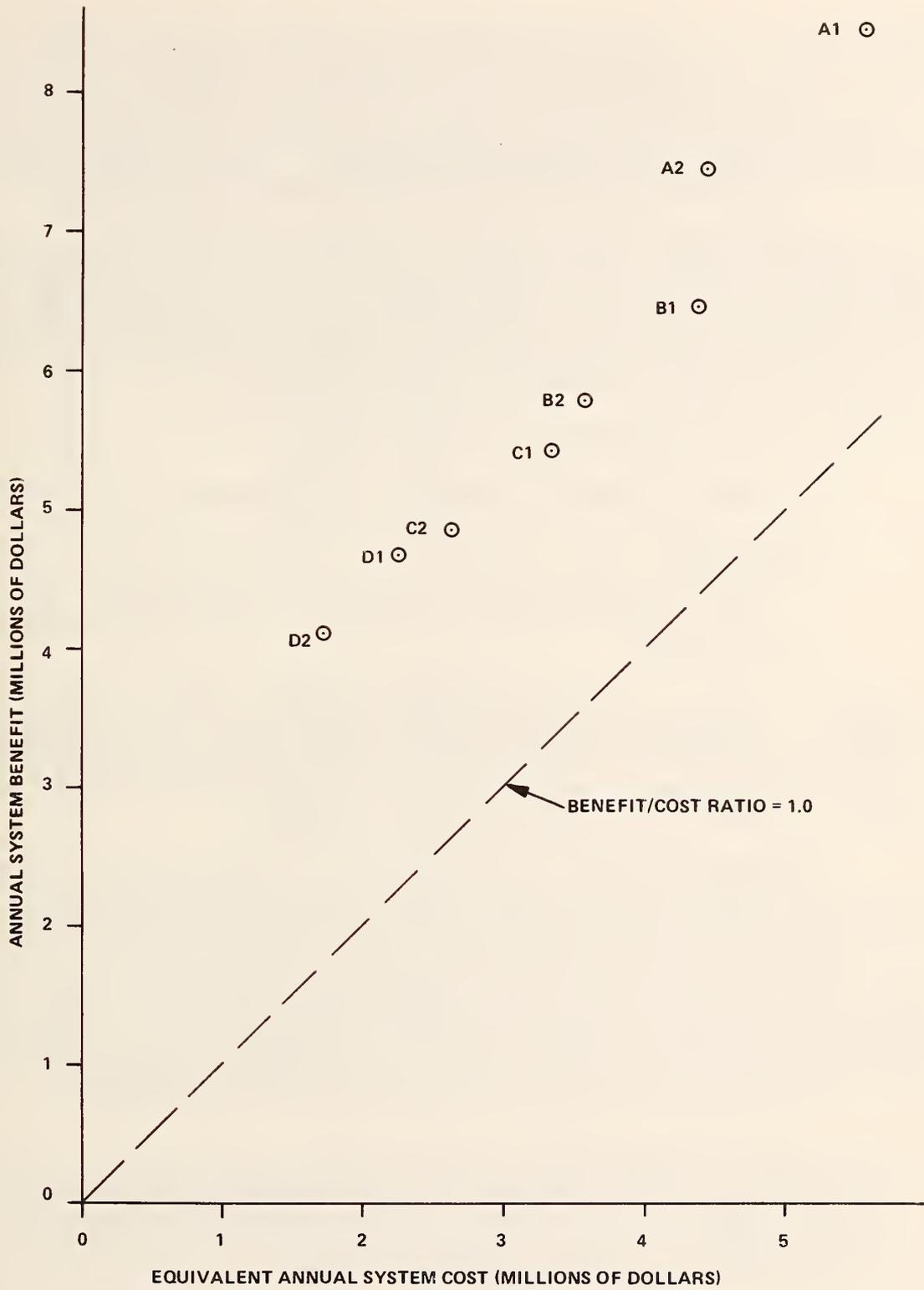


Figure 22. Benefits vs. Costs For Candidate Systems

Using the lowest cost system as the baseline, the incremental cost, benefit, and benefit/cost ratio are computed for the next system. The process is continued until a system is reached which produces an incremental benefit/cost ratio greater than 1.0. At this point, that system becomes the new baseline and the remaining systems are evaluated relative to it. Again, the process is continued, changing the baseline as indicated, until all systems have been considered. The final baseline system used is the "best" system from the incremental benefit/cost point of view.

This procedure has been applied to the eight candidates systems and the results are presented in Table 46. The first calculation showed that System D1 had an incremental benefit/cost ratio greater than 1.0. It thus replaced system D2 as the baseline. Subsequently, System A2 produced an incremental ratio greater than one. It, therefore, became the new baseline and remained as the final one. Thus System A2 is "best" on the basis of incremental benefit/cost ratio.\*

### 16.3 DISCUSSION OF BENEFIT/COST EVALUATION

As a result of the benefit/cost analyses, the following may be concluded:

- On a straight benefit/cost ratio basis, candidate system D2 is the best choice;
- On an incremental benefit/cost ratio basis, candidate system A2 is the best choice.

The latter two results are not conflicting, but rather represent two different evaluation philosophies. The first seeks to obtain the maximum return on the investment, while the second considers further investment to be warranted as long as the additional benefits continue to exceed the additional cost (up to any cost constraint that may be imposed). Is one philosophy always superior to the other?

It is felt that the answer to this question must be "no". Instead, rational judgement must be exercised when the two approaches yield different results. For example, consider a rather extreme case. A ramp metering "system" in Atlanta consists of a single metered ramp. The equivalent annual cost is \$500 and the annual benefit is \$24,400, yielding a benefit/cost ratio of 49.\*\* This is an extremely high return on the investment, and would be a sound choice if only a "spot" improvement is needed. But suppose many other ramps should also be metered to address an overall freeway problem, and the total benefit/cost ratio for this case was significantly less (say 10). Should not the overall problem be addressed?

-----  
\* It is noted that the benefit/cost ratios (B/C) of the various alternative designs and their relative incremental B/C can be analyzed graphically from the benefit versus cost plot (Figure 22). The slopes of the lines connecting the points to the origin are the benefit/cost ratios, while the slopes of the lines connecting any two points are their relative incremental benefit/cost ratios.

\*\* Data from "Urban Freeway Surveillance and Control, The State of the Art", by Paul F. Overall, June 1973 (Revised Edition)

Table 46. Incremental Benefit/Cost Evaluation

A. INCREMENTAL B/C RATIOS USING SYSTEM D2 AS A BASE						
<u>System</u>		<u>Cost</u>	<u>Benefit</u>	<u>Increment. Cost</u>	<u>Increment. Benefit</u>	<u>Increment. B/C Ratio</u>
D2	Basic	1.723	4.097			
D1		2.270	4.676	0.547	0.579	1.06 *
C2		2.633	4.831			
C1		3.345	5.405			
B2		3.586	5.775			
B1		4.385	6.451			
A2		4.493	7.445			
A1		5.577	8.474			
B. INCREMENTAL B/C RATIOS USING SYSTEM D1 AS A BASE						
D1	Basic	2.270	4.676			
C2		2.633	4.831	0.363	0.155	0.43
C1		3.345	5.405	1.075	0.729	0.68
B2		3.586	5.775	1.316	1.099	0.84
B1		4.385	6.451	2.115	1.775	0.84
A2		4.493	7.445	2.223	2.789	1.25 *
A1		5.577	8.474			
C. INCREMENTAL B/C RATIOS USING SYSTEM A2 AS A BASE						
A2	Basic	4.493	7.445			
A1		5.577	8.474	1.084	1.029	0.95

\*Becomes new base system

On the other hand, this reasoning can be carried too far, as well. Excessive funds can be spent on one project at the expense of others, simply because it is still returning more than a dollar for each dollar spent.

Although the above are perhaps extreme examples, they serve to point out that the decision should not be a mechanical one, particularly in the case of IMIS. Instead, needs must be addressed in conjunction with priorities if a proper system selection is to be made. Both forms of benefit/cost analysis provide input to this process.

Some further discussion of the specific candidates is in order. The two leading candidates, A2 and D2, are widely differing systems in size. System A2 covers the entire test corridor, despite the fact that major portions (particularly the eastern half) do not have severe congestion problems. System D2 is limited to the south-west quadrant of the corridor where the major congestion problems exist.

Both systems have minimum equipment complements, e.g., 1 mile (1.6 km) detector spacing, few variable message signs (mostly replaced by highway advisory radio), half-time manning of the control center, single computer, etc. Nevertheless, there is a wide cost variation between the two, due to physical size, as noted below:

<u>System</u>	<u>Initial Capital Cost</u>	<u>Annual Maint &amp; Ops</u>
A2	\$28,335,000	\$768,000
D2	9,398,000	487,000

Obviously, funding availability could be the governing factor in a decision. Should the larger system be desired, and present funds not be sufficient, the system could be installed in stages. The results of the benefit/cost analyses would be useful to provide guidance on the staging process.

Suppose that the larger system was not desired, either from a cost or operational point of view. Before a final selection of System D2 is made, further consideration should be given to System D1. One reason is that costs for several of the D1 features have been included without assigning benefits to them. (Examples: full-time staffing of control center, dual computers, pre-trip/enroute information service.) This is partially responsible for its somewhat lower benefit/cost ratio. Are these features considered important to the operating jurisdiction? Further, are there other features which are desired based on experience (e.g. the closer detector spacing)? If so, then perhaps System D1 is the better choice.

In summary, the benefit/cost analyses and associated system configurations should be considered as inputs to the system selection process. The final selection must be made by the user, based on due consideration of all related factors.

## 16.4 BENEFIT/COST SENSITIVITY ANALYSIS

Normally the benefit/cost sensitivity is of primary interest for the selected system, although it can also be performed for other "close" candidates. In the present study, no specific candidate has been selected. However, since System A2 has the lowest benefit/cost ratio (1.66) of the "better" candidates, the analysis is most important to, and therefore performed for this case.

Table 47 identifies the set of factors which have a major impact on benefit and cost variations. The first eight of these affect system benefits, while the last three affect system costs.

The procedure used is to treat each group separately and subsequently combine the uncertainties to arrive at the overall variations. Basically, an error analyses approach can be used to relate the total benefit or cost error to the errors in their component quantities (Table 47). Under the assumption that the factors are independent, the total benefit or cost sensitivity is obtained by taking the square root of the sums of the squares of the deviations caused by the individual variations due to each component. This general procedure is applied to the benefit and cost relationships respectively in the following paragraphs.

### 16.4.1 Benefit Sensitivity Analysis

The yearly system benefit, in dollars, is defined by the following equation:

$$\begin{aligned} \$B = (\$VD) & \left[ (KI_p) (VDB_{Ip}) + (KI_{op}) (VDB_{Iop}) + VDBY_c + (ARBY) (VDB_a) \right] \\ & + (\$F) (FBY) + (\$AC) (ARBY) \end{aligned} \quad (40)$$

where:

- \$B - Yearly system benefit (dollars)
- $VDB_{Ip}$  - Delay saved/peak period incident - 1, 2, 3\*
- $VDB_{Iop}$  - Delay saved/off-peak period incident - 1, 2, 3
- $KI_p$  - Yearly total lane blocking incidents peak period - 6
- $KI_{op}$  - Yearly total lane blocking incidents off-peak period - 6
- $VDBY_c$  - Annual delay saved, normal congestion
- $VDB_a$  - Delay saved/accident
- $\$VD$  - Benefit/vehicle-hour delay saved - 4

-----  
\*Numbers which follow the definitions are cross references to the factors given in Table 47.

Table 47\*. Benefit/Cost Sensitivity Factors

●	Benefit Factors
	(1) Motorist Response to Advisory Signing
	(2) Average Incident Detection Time
	(3) Average Time to Clear Incident
	(4) Value of Motorist's Time (dollar)
	(5) Cost of Accidents (dollar)
	(6) Accident Frequency
	(7) Fuel Saved
	(8) Value of Fuel (dollar)
●	Cost Factors
	(9) Interest Rate
	(10) Useful Life
	(11) Component System Costs

\*This table appears in the Handbook as Table 53.

\$AC	-	Benefit/accident saved - 5
FBY	-	Yearly total fuel saved - 7
\$F	-	Benefit/gallon fuel saved - 8
ARBY	-	Yearly reduction peak period accidents - 6

The computation of benefit sensitivity is affected by the relationship of each component to the benefit and the expected variation of each component. Each of these relationships can ultimately be put in the form:

$$\Delta B_x = a_x (\Delta X) \quad (41)$$

Utilizing the general relationship, the variation in each component ( $\Delta X$ ) makes a distinct contribution ( $\Delta B_x$ ) in the overall benefit uncertainty. The sensitivity coefficient for each component ( $a_x$ ) is unique for each component. Table 48 gives the sensitivity coefficients for each of the components given in equation 40.

Following the above procedure, the sensitivities of the quantities defined in Table 48 were computed using the sensitivity coefficients,  $a_x$ , defined in that table. The benefit values used in the computation of the sensitivity coefficients were derived from the results of Section 15 and are given in Table 49. The numerical values of the sensitivity coefficients associated with each component are given in Table 50. For the present study, a 10 percent variation in each of the components of Table 48 was used.

Table 48. Sensitivity Coefficients\*

Component ( $\Delta X$ )	COEFFICIENTS ( $a_x$ )**
$VDB_{Ip}$	$\$VD(KI_p)$
$VDB_{Iop}$	$\$VD(KI_{op})$
$KI_p$	$\$VD(VDB_{Ip})$
$KI_{op}$	$\$VD(VDB_{Iop})$
$\$VD$	$(KI_p) (VDB_{Ip}) + (KI_{op}) (VDB_{Iop}) + (VDBY_c) + (ARBY) (VDB_a)$
$\$AC$	ARBY
FBY	$\$F$
ARBY	$\$VD(VDB_a) + \$AC$

\*This table appears in the Handbook as Table 54.

\*\*The coefficients for each component are determined by inspection of Equation 40.

Table 49. Values Used in Benefit Sensitivity Analysis

	<u>West of</u> <u>I605</u>	<u>East of</u> <u>I605</u>	<u>Total</u>
$KI_p$	790	344	1134 Veh hrs.
$KI_{op}$	1586	644	2230 Veh hrs.
$VDB_{Ip}$	722	753	1475 Veh hrs.
$VDB_{Iop}$	174	83	257 Veh hrs.
$VDBY_c$			711671 Veh hrs.
ARBY			83 Accidents
$\$VD$			\$3.50
$\$FD$			\$0.65
$\$AC$			\$3400

Table 50. Computation of Sensitivity Coefficients for System A2

Component ( $\Delta X$ )	Coefficient $a_x$				Total W & E (\$)
	West of I-605 Computation	Value (\$)	East of I-605 Computation	Value (\$)	
VDB <sub>Ip</sub>	\$3.50 x 790	2765	\$3.50 x 344	1204	3969
VDB <sub>Iop</sub>	3.50 x 1586	5551	3.50 x 644	2254	7805
KI <sub>p</sub>	3.50 x 722	2527	3.50 x 753	2635	5162
KI <sub>op</sub>	3.50 x 174	609	3.50 x 83	291	900
\$VD	790 x 722 + 1586 x 174	846,344	344 x 753 + 644 x 83	312,484	
		(+ 711, 671 + 83 x 776)*			1,934,907
\$AC					83
FBY					0.65
ARBY		\$3.50 (776) + \$3400			6116

-----  
\*Values Not Available by Section; Therefore Only Total Is Given.

The changes in benefits ascribed to these variations were computed using the sensitivity coefficients, and the results of these computations are summarized in Table 51.

The total expected variation in system benefits was then computed according to the equation

$$\Delta B = \left[ \sum_x (\Delta B_x)^2 \right]^{1/2} \quad (42)$$

and the result is \$1.11 million.

#### 16.4.2 Cost Sensitivity Analysis

The benefit/cost ratio is sensitive to variations in interest rates, assumed useful life, and cost estimates. The variations assumed for interest rates is  $10 \pm 2$  percent per year, which provides a reasonable range of values about the nominal rate (10 percent). Useful life variation is assumed to be  $15 \pm 5$  years, which covers

Table 51. Changes in Benefit as a Result of Component Variation

	Nominal	Variation	$\Delta$ Benefit	% Total Benefit *	$\Delta B^2 (x10^{10})$
VDB <sub>Ip</sub>	1475	147	147 x 3969 = 583,443	7.8	34.0
VDB <sub>Iop</sub>	257	26	26 x 7805 = 202,930	2.7	4.1
KI <sub>p</sub>	1134	113	113 x 5162 = 583,306	7.8	34.0
KI <sub>op</sub>	2230	223	223 x 900 = 200,700	2.7	4.0
\$VD	3.50	0.35	0.35 x 1,934 x 10 <sup>6</sup> = 676,900	9.1	45.8
\$AC	3400	340	340 x 83 = 28,220	0.38	0.078
FBY	1,667,405	166,740	.65 x 166,740 = 108,381	1.5	1.17
ARBY	83	83	8.3 x 6116 = 50,763	0.68	0.26
			$\Delta B = (123.4 \times 10^{10})^{1/2} = \$1.111 \text{ MILLION}$		<u>123.4 x 10<sup>10</sup></u>
*Total Benefit = \$7,445,093					

the life expectancy range of most electronic equipment and associated hardware. Cost-estimate variations are assumed to be  $\pm 20$  percent about the estimated capital, maintenance and operational cost values, reflecting uncertainties in costs of labor and materials.

The approach used is to compute the costs and benefit/cost ratios for each pair of limits while holding the other cost elements at their nominal values. The resulting differences between these values and their corresponding nominal values are then root-sum-squared to provide an estimate of the overall benefit/cost change.

The computation required conversion of the capital cost estimates to equivalent values, using the capital recovery factors (CRF) applicable to each interest rate and useful life value. Table 52 shows the results of the computational steps for System A2. Baseline values shown in the table are based on 10 percent interest rate, 15 years useful life and nominal cost estimates developed in Section 13. The equivalent annual capital costs are added to the maintenance and operational costs for each of the cost elements variations, and these totals are subtracted from the baseline total to give the individual cost element differences.

To obtain the overall cost sensitivity, the cost differences for each category are averaged, and the square root of the sums of their squares is computed. The resulting value is \$1.184 million.

#### 16.4.3 Benefit/Cost Ratio Variation

The variation of the benefit/cost ratio due to both cost ( $\Delta C$ ) and benefit ( $\Delta B$ ) variations is computed using the following equation:

$$\begin{aligned} \Delta(B/C) &= \left[ (\Delta B/C)^2 (B/C)^2 + (\Delta C/C)^2 \right]^{1/2} & (43) \\ &= \left[ (1.111/4.493)^2 + (7.445/4.493)^2 (1.184/4.493)^2 \right]^{1/2} \\ &= 0.502 \end{aligned}$$

#### 16.4.4 Discussion

Table 51 serves to highlight those parameters whose variation from the nominal most influence the total system benefit. Ten percent variations in  $VDB_{Ip}$  (Delay, saved/peak period incident),  $KI_p$  (Yearly total lane blocking incidents, peak period) and \$VD (Benefit/vehicle hour delay saved), result in changes to the total benefit of 7.8, 7.8 and 9.1 percent respectively, while the same magnitude variation in other parameters results in benefit changes of less than 2.7 percent. This implies that particular attention should be given to accurate determination of the three parameters to which the benefit computation is most sensitive.

Table 52. Cost Element Variations for System A2

Factor	Baseline Value*	Interest Rate 8%	Interest Rate 12%	Useful Life (20 YRS)	Useful Life (10 YRS)	Cost Estimate (-20%)	Cost Estimate (+20%)
Capital Recovery Factor (CRF)	0.1315	0.1168	0.1468	0.1175	0.1628	-	-
Equivalent Annual Capital Cost (M\$)	3.725	3.310	4.160	3.329	4.613	2.980	4.470
Ann. Maint. & Oper. Cost (M\$)	0.768	0.768	0.768	0.768	0.768	0.614	0.922
Total Annual Cost (M\$)	4.493	4.078	4.928	4.097	5.381	3.594	5.392
Cost Differences (M\$)	-	0.415	0.435	0.396	0.888	0.899	0.899
Capital Cost = 28.335 (M\$)							

\*Based on 10 percent interest rate and 15 year useful life.

For the ranges of values used in the cost sensitivity analysis, it can be seen (Table 52) that the accuracy of the system cost estimate is most sensitive to the capital cost estimate and less so to the estimates of system life and interest rate.

Overall, the potential variation in the benefit/cost ratio was found to be 0.502. Thus, the benefit/cost ratio for System A2 may be considered as  $1.66 \pm .50$ , or to range from 1.16 to 2.16. Thus, the system would still be considered a viable candidate in this case.

Ordinarily, after completion of the benefit/cost analyses the user is in a position to reach a conclusion regarding the feasibility of IMIS in his corridor, and if feasible, to select a system for the next stage of the project (final design/PS&E). If the user had performed the present study, the results obtained would provide a basis for concluding that IMIS is feasible in this corridor.

## SECTION 17

### CONCLUSIONS

The major output of the IMIS Phase II study was a user Handbook for performing an IMIS feasibility study in any corridor. The present report, covering the final Phase II task, has presented the results of applying the Handbook to a real-world corridor with the objective of establishing its workability and validity.

The application exercise proved to be quite useful in uncovering certain problems which were not evident during the initial writing of the Handbook. For example, the original route evaluation process appeared to work well for a simplified hypothetical example. It was found, however, to be somewhat inadequate for the more complex situation of the real world case. In particular some of the "weighting" factors and scales were found to be producing improper sensitivities, and certain criteria were inappropriate in their given form. Thus, a fairly extensive revision was made to this chapter. Other revisions to the Handbook were made, as typified by the following additional examples:

- Simplification of the trip length computation - It was found that the original rather complex graphical presentation was not necessary, in that results could be read directly from a table.
- Clarification of control subnetwork definition - The definitions were re-stated in terms of generic types with corresponding examples, to provide a more generalized procedure.
- Revisions in communications subsystem study - It was found that procedures for computing a required intermediate output had not been given. Also, certain computations originally specified on an overall basis were changed to an individual roadway basis so that alternative designs could be more quickly evaluated.
- Clarification of the incremental benefit/cost analysis - The original procedures were not fully defined.

Many other useful comments and suggestions were provided by the Federal Highway Administration as a result of their review of the draft copy of the Handbook. The Handbook was appropriately modified to incorporate these inputs as well.

The results of the simulation effort for validating the basic benefit relationships (Appendix A) revealed that the Handbook methodology can be expected to provide a reasonably accurate measure of system benefits.

The overall conclusion of the study, then, is that the Handbook (as revised) represents a viable tool for conducting an IMIS feasibility study in any corridor. The Handbook does not and cannot reduce such a study to a totally mechanical pro-

cess. Rather, it defines what should be done and provides procedures and guidelines for accomplishing each step. User judgement is a necessary ingredient throughout the study.

The present application of the Handbook to a test corridor should provide a useful reference to users of the Handbook, in that it represents a complete example of a feasibility study. It should be recognized that the specific results obtained should not be construed as a final determination of IMIS feasibility in the test corridor, since this was not the study objective. Nevertheless, the study was a rather comprehensive one and should serve at least as an indicator that IMIS has a high potential to be cost-effective in the test corridor.

## APPENDIX A

### VALIDATION OF FUNDAMENTAL BENEFIT RELATIONSHIPS

#### A.1 INTRODUCTION

The benefit determination procedures contained in the Handbook were developed with the aid of an extensive set of computer simulation runs (approximately 150) performed during the IMIS Phase I study. The procedures constitute a critical element of the system evaluation process, and as such, it must be verified that they are sufficiently free of site-specific influences and sufficiently accurate to allow their general use in any IMIS feasibility study.

The approach used to validate the benefit determination procedures was to utilize a computer simulation (SCOT model) of a network in the test corridor to develop an independent set of benefit data. These results then serve as "check points" against which the methodology results may be compared and evaluated.

Fundamental sizing constraints of the SCOT model dictated the size of the network that could be simulated, consistent with maintaining a high degree of simulation fidelity. Within these constraints, it was found that network configuration D (used for two of the alternative designs) could be accommodated with a minor SCOT modification. This network, shown in Figure 23, represents the most congested portion of the corridor, and further, permits all of the IMIS control functions to be exercised. Thus, it represented a logical choice for the present test.

The following paragraph provides a further discussion of the simulation network and describes the structured set of simulation runs used for the validation task. The final paragraph presents the results of the comparison between the simulation-derived and methodology-derived benefit data.

#### A.2 SIMULATION NETWORK AND SCENARIOS

The simulation network (Figure 23) is composed of two major east-west freeways (I-10, Cal 60), two parallel arterials (Valley Blvd., Garvey Ave.), and several freeway and arterial connectors including I-5, U.S. 101, I-605, Cal 7, Atlantic Blvd., and Rosemead Blvd. As such, it provides the opportunity to exercise the full complement of IMIS control functions, including route diversion, ramp metering, and arterial signal control.

The western end of the network includes a series of major freeway-to-freeway interchanges between I-10, I-5, Cal 60, and U.S. 101. Thus, it serves as a collector-distributor for the traffic movements on I-10 and Cal 60. Total volumes in the western end of network, which includes freeway sections containing 10 and 12 lanes, are considerably higher than those found on most typical freeways.



The combination of interchange geometry and high volumes in the western end of the corridor imposed a heavy drain on the simulation's vehicle handling capability. Through analysis it was in fact determined that the entire simulation network could not be accommodated by the existing SCOT model without extensive network simplification. Such simplification was considered undesirable since it could affect the credibility of the test. Therefore, the SCOT model was modified, increasing its vehicle array size from 4000 elements to about 8000 elements. This provided the necessary capability to incorporate the entire simulation network with a high degree of fidelity. The simulation was then calibrated to the test corridor using the special data collected during the field trip.

The scenarios used for the simulation runs were based on the PM-peak operational and flow characteristics of the network. The basic volume levels and turning fractions were developed from the data base collected during the study. Table 53 lists the complete set of simulation runs made, including those required for preliminary analysis.\* The structuring of the runs was based on the need to develop two experiments - a normal congestion experiment and an incident congestion experiment. The formulation of each experiment included an evaluation set consisting of:

- A baseline run - A short run (typical duration 15 min) to establish the nominal traffic conditions with respect to which the other runs are compared.
- A problem run without control - a full length run (typical duration 60 min) to determine the uncontrolled response of the traffic network to the occurrence of a major congestion event. Typical events are lane-blocking incidents or a build up of normal congestion.
- A problem run with control - a full length run (typical scenario duration of 65 minutes) to determine the controlled response of the traffic network to minimize the effects of the major congestion event.

In general, more than one control run is made (typically, 2 to 4 runs) in order to obtain the sensitivity of system response to a range of control levels. For the normal and incident congestion experiments, four control runs were made in each case. (See Table 54).

The problem run without control for the normal congestion experiment created extensive roadway congestion on the I-10 freeway for the 9 mile (14.4 km) section from the Cal 7 interchange east to the Garvey Ave. interchange. Creating

- - - - -

\*The preliminary analysis runs, indicated by an asterisk in Table 53, were necessary to establish appropriate flow levels for the desired scenarios, since dynamic conditions throughout the network cannot be determined in advance. Analysis of the preliminary runs leads to the input changes required to produce (approximately) the flow levels sought for the scenarios.

Table 53. Listing of Simulation Runs

Identification	Scenario Time Simulated (Minutes)	Run Description
#1	15	Baseline*
#2	15	Baseline (Replaces Run #1)
#3	65	Normal Congestion without Control ● Congestion - moderate*
#3-A	65	Normal Congestion without control ● Congestion - heavy (Replaces Run #3)
#3-A.1	65	Normal Congestion with control - Based on #3-A ● Congestion - moderate
#3-A.2	65	Normal Congestion with control - Based on #3-A ● Congestion - light
#3-A.3	65	Normal Congestion with control - Based on #3-A ● Congestion - heavy
#3-A.4	65	Normal Congestion with control - Based on #3-A ● Congestion - extra light
#4	65	Incident Congestion without control ● Congestion - very heavy*
#4-A	65	Incident Congestion without control ● Congestion - heavy (Replaces Run #4)
#4.1	65	Incident Congestion with control - Based on #4 ● Congestion - moderate*
#4.2	65	Incident Congestion with control - Based on #4 ● Congestion - heavy*
#4.3	65	Incident Congestion with control - Based on #4 ● Congestion - very heavy*
#4-A.1	65	Incident Congestion with control - Based on #4-A ● Congestion - heavy
#4-A.2	65	Incident Congestion with control - Based on #4-A ● Congestion - moderate
#4-A.3	65	Incident Congestion with control - Based on #4-A ● Congestion - heavy, length of control period reduced
#4-A.4	65	Incident Congestion with control - based on #4-A ● Congestion - moderate, length of control period reduced

\*Used for preliminary analysis only.

Table 54. Validation Experiments

	Normal Congestion Experiment	Incident Congestion Experiment
● Baseline Run	No. 2	No. 2
● Problem Run without Control	No. 3-A	No. 4-A
● Problem Run with Control		
Control Level	No. 3-A.1 No. 3-A.2 No. 3-A.3 No. 3-A.4	No. 4-A.1 No. 4-A.2 No. 4-A.3 No. 4-A.4

this congestion was accomplished by simulating an above normal (i.e., high demand) volume level for the first 30 minutes of the run. The last 30 minutes of the run were used to monitor roadway performance after the transients had subsided. This same time period was used as the period of observation for each of the control runs.

The problem run without control for the incident congestion experiment was based on a one-lane blockage of the Cal 60 roadway in the vicinity of the Rosemead Blvd. interchange. The blockage remained on the roadway for 30 minutes at which point it was cleared, with the run continuing for another 25 minutes. For all runs in this experiment the entire period from incident occurrence until the simulation terminates was used as the period of observation. Control was implemented 5 min. after incident occurrence to simulate the time lag of a surveillance system based on 1/2 mile (.8 km) detector spacing.

### A.3 COMPARISON OF SIMULATION AND METHODOLOGY BENEFIT DATA

The dynamic nature of the simulation model and scenarios is such that flow conditions throughout the network cannot be a priori specified, but rather must be determined after the simulation run has been completed. Thus, in order to obtain a proper benefit comparison between the methodology output and the simulation output, the flow conditions produced by the simulation are used as the baseline, i.e., the methodology is applied to these conditions and the resulting benefit levels are compared to those produced by the simulation.

The equation used in the methodology for the congestion benefit computation is of the following form:

$$VDB = D_{ss} \left[ (1 - e^{-.01\Delta Q}) - \beta (.01\Delta Q) e^{-.01\Delta Q} \right] \quad (16)$$

where: VDB = Predicted delay benefit (veh. hrs/hr/lane-mile)

D<sub>ss</sub> = Theoretical maximum benefit (veh. hrs/hr/lane-mile)

$$= \bar{Q} \left( \frac{U_{ff} - U_c}{U_{ff}} \right), \text{ where } \bar{Q} \text{ is the mean flow per lane}$$

per hour,  $U_c$  is the mean congested roadway speed,  
 $U_{ff}$  is the free-flow speed (assumed 55 mph (89 kmph))

$\Delta Q$  = Control volume shift (veh/lane/hr)

$\beta$  = Congestion severity factor (a function of  $U_c$ , as specified in Chapter 15 of the Handbook)

For the normal congestion experiment, the simulation provided a mean flow value ( $\bar{Q}$ ) of 1680, veh/lane/hour and a mean congested speed of 38.4 mph (61.8 kmph). Control volumes shifts were determined by comparing the mean flow levels for each control run (3-A.1, 3-A.2, 3-A.3, 3-A.4) with that of the basic run without control (3-A). The resulting values were 237, 123, 286, and 89 veh/lane/hr, respectively.

The simulation-derived benefits were obtained through a comparison of each control run with the "no control" case. The methodology-derived benefits were calculated from Equation 16 using the above data produced by the simulation. By using the same values of control volume shift ( $\Delta Q$ ) in both the methodology and the simulation, the variation of benefits with  $\Delta Q$  is accounted for, and a proper comparison of differences can be made.

To determine the significance of the observed differences between the methodology and simulation results, the "t" statistic was used. Table 55 presents the two data sets together with the observed differences. Also shown is the associated "t" statistic for the differences. Based on the value of the statistic, the available evidence indicates that there is no reason at the 5 percent significance level to reject the null hypothesis and attribute the differences to other than random variations. (There is some further discussion of the analysis in paragraph A.4.)

The incident congestion benefit relationship was considered in the same manner as outlined above. The incident characteristics were one lane blocked for a time interval of 30 minutes, beginning at  $t = 10$  minutes into the run. The total interval of observation was 55 minutes.

Comparison of the mean flow level for each control run (4-A.1, 4-A.2, 4-A.3, 4-A.4) with respect to the flow level of the "no control" run (4-A) resulted in a mean control volume shift,  $\Delta Q$ , for each control run of 377, 295, 354, and 247 veh/lane/hr, respectively. A second variational factor included in the control policy was the time interval over which the policy was implemented. For runs 4-A.1 and 4-A.2 the interval was 50 minutes and for runs 4-A.3 and 4-A.4 the interval was 30 minutes. The control policy for each run was instituted 5 minutes after incident occurrence.

Table 55. Comparison Of Normal Congestion Benefit Data

Run No.	$\Delta Q^*$	Simulation Benefit	Methodology Benefit	Diff
3-A & 3-A.4	89	3.2	6.6	3.4
3-A & 3-A.2	123	7.2	8.2	1.0
3-A & 3-A.1	237	10.7	11.3	.6
3-A & 3-A.3	286	12.5	11.9	-.6

't' Statistic  

$$t = \frac{\sqrt{N(N-1)} \bar{X}}{(\sum (X_i - \bar{X})^2)^{1/2}}$$
 with 3 DOF

(Benefit data units are vehicle-hours/hour/lane-mile)

-----

\*The values of  $\Delta Q$  are shown for reference.

Computation of the methodology derived benefits for incident congestion followed the procedure given in Chapter 15 of the Handbook. Table 56 presents the benefit data sets for this comparison. The observed differences and 't' statistic are also given. Based on the value of this statistic there is again no reason (at the 5 percent significance level) to reject the null hypothesis.

#### A.4 DISCUSSION

As a result of the FHWA Contract Manager's review of the draft Validation and Application report, he offered several comments on the foregoing validation analysis and results. It is considered appropriate to include them in this report, and, therefore, they are discussed in the following paragraphs.

One comment was related to the fact that only a limited number of usable data points were available from each experiment for the statistical analysis (each of the 't' tests involved three degrees of freedoms). Under these conditions, the conservative nature of the 't' test is such that rather large differences would be required to result in rejection of the null hypothesis. We concur with this comment, and recognize that the tests have not proved that there is no difference, but rather that the observed differences were not large enough (considering the sample size) to provide conclusive evidence to the contrary. For the given tests, however, no other conclusions can be drawn other than those presented, i. e., the tests did not provide a reason to reject the null hypothesis.

The methodology represents a combined analytical/empirical model which predicts the changes in vehicle-hours of delay resulting from changing demands (e. g. through diversion). The analytical portion of the model is based on traffic flow theory. The empirical portion is based on a large set of computer simulation runs (about 150 runs, covering many scenarios and various roadway configurations). The study staff feels, therefore, that in addition to the statistical tests performed there is an additional measure of confidence in the methodology (albeit in an heuristic sense) based on the development itself.

Returning to the type of statistical test used, it was suggested that a more appropriate test might be one based on the ratio of the methodology results to the simulation results (rather than the differences), using the null hypothesis that the ratios are not different from 1.0. (The analysis was in fact provided by the Contract Manager). The resulting values of the 't' statistics were slightly lower than those obtained based on differences, therefore leading to the same conclusions. There is, of course, no claim made that this increases the level of confidence in any way. Rather, had the results been different, further analysis would have had to have been undertaken to ascertain the reason.

In using the ratio form of the test, the Contract Manager perceived that there appeared to be a negative correlation of the ratios with  $\Delta Q$  (although a statistical analysis was not performed). That is, at the lower values of  $\Delta Q$  the higher ratios were observed, with the ratios generally decreasing as  $\Delta Q$  increased. We again concur with this observation. If it should be the case, we do not feel it represents a significant problem since from the practical point of view, small values of  $\Delta Q$  cannot produce substantial benefits. Thus, a feasibility study outcome will generally be

Table 56. Comparison of Incident Congestion Benefit Data

Run No.	$\Delta Q^*$	Simulation Benefit	Methodology Benefit	Diff
4-A & 4-A.1	377	97.1	92.9	- 4.2
4-A & 4-A.2	295	73.3	84.0	+10.7
4-A & 4-A.3	354	89.	91.3	2.3
4-A & 4-A.4	247	68.	68.7	.7

't' Statistic  

$$t = \frac{\sqrt{N(N-1)} \bar{X}}{(\sum (X_i - \bar{X})^2)^{1/2}}$$
 t = .777  
 with 3 DOF

(Benefit data units are vehicle-hours/hour/lane-mile)

\*The values of  $\Delta Q$  are shown for reference.

insensitive to errors (within reason) for these cases. In other words, if there is sufficient congestion in a corridor to consider an IMIS installation, but very little hope of achieving a reasonable level of control volume shift capability, the cost of IMIS will not be justifiable. The feasibility study will provide that answer even if the methodology should "exaggerate" the small benefits achievable. Similarly, if the methodology should produce benefits which are slightly low for the large values of  $\Delta Q$ , the results will be somewhat conservative, but not to the extent of altering the study outcome.

Finally, it was commented that since the comparison was made between the methodology and a simulation model, it cannot simply be stated that the methodology relationships represent real-world relationships. We again concur. However, since real-world "before and after" benefit data are not available, we consider the simulation (SCOT) model to be the best surrogate available. Further, we feel that the model (which has been validated) is sufficiently accurate to call it a good representation of the real-world case.

In conclusion, the study staff considers the benefit determination methodology to be a suitable evaluation tool for use in IMIS feasibility studies.

TE	662
.A3	
no. FHWA-RD-	
78-24	BORROW
c.2	
<i>Chinnery</i>	
<i>LC Allen</i>	
<i>[Signature]</i>	

## **FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)**

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote to these projects.\*

### ***FCP Category Descriptions***

#### **1. Improved Highway Design and Operation for Safety**

Safety R&D addresses problems connected with the responsibilities of the Federal Highway Administration under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

#### **2. Reduction of Traffic Congestion and Improved Operational Efficiency**

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by keeping the demand-capacity relationship in better balance through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

#### **3. Environmental Considerations in Highway Design, Location, Construction, and Operation**

Environmental R&D is directed toward identifying and evaluating highway elements which affect the quality of the human environment. The ultimate goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

#### **4. Improved Materials Utilization and Durability**

Materials R&D is concerned with expanding the knowledge of materials properties and technology to fully utilize available naturally occurring materials, to develop extender or substitute materials for materials in short supply, and to devise procedures for converting industrial and other wastes into useful highway products. These activities are all directed toward the common goals of lowering the cost of highway construction and extending the period of maintenance-free operation.

#### **5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety**

Structural R&D is concerned with furthering the latest technological advances in structural designs, fabrication processes, and construction techniques, to provide safe, efficient highways at reasonable cost.

#### **6. Prototype Development and Implementation of Research**

This category is concerned with developing and transferring research and technology into practice, or, as it has been commonly identified, "technology transfer."

#### **7. Improved Technology for Highway Maintenance**

Maintenance R&D objectives include the development and application of new technology to improve management, to augment the utilization of resources, and to increase operational efficiency and safety in the maintenance of highway facilities.

\* The complete 7-volume official statement of the FCP is available from the National Technical Information Service (NTIS), Springfield, Virginia 22161 (Order No. PB 242057, price \$45 postpaid). Single copies of the introductory volume are obtainable without charge from Program Analysis (HRD-2), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.

DOT LIBRARY  
00056243

